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TWO-HANDED, WHOLE-HAND INTERACTION

by

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September 1998

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The thesis presents the background for these two areas of research, taxonomies and whole-hand interaction. It goes on to develop a taxonomy and classification of two-handed, whole-hand interaction for the real world and virtual environments. This taxonomy is used to analyze a large number of real world tasks, to further the development of a series of tests to externally validate the classification, and to analyze the tasks of the 91B Field Medic. This thesis further presents recommendation for how this methodology can be used to develop taxonomies for other areas of human interaction, for how this taxonomy can be used by researchers and practitioners, and areas of further research related to both areas.

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TWO-HANDED, WHOLE-HAND INTERACTION

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ABSTRACT

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I. TWO-HANDED, WHOLE-HAND INTERACTION

A. INTRODUCTION

The first goal of this paper is to describe a classification of human ability requirements (HARs) that serve to structure the human interaction research presently being performed in the real world and in Virtual Environments (VEs) into a complete and coherent framework. "Until recently, the VE community has been occupied with getting any input to work, but it is now maturing to the point that finding common techniques across applications is appropriate."[17] This classification methodology, or taxonomy, can then be used to better understand human interaction techniques already seen in the literature and to develop new interaction techniques that are related to existing ones in terms of human performance. The methods and classifications presented have not been developed in a vacuum, but have instead been derived from a well defined taxonomic methodology based on human ability requirements.[23] This paper introduces how this taxonomy can be used to analyze tasks performed in the real world and these same tasks performed on a new device for interaction in VEs. The classification elucidates the strengths and weaknesses of the device in terms of a user's ability to perform the actual tasks in the VE.

The second focus of this paper examines the topic of two-handed, whole-hand (THWH) interaction. THWH interaction is the dominant manner in which humans discover and change the world around them.[46] As these methods of interaction are adopted in advanced computer systems, as input and output for Graphical User Interfaces (GUIs) or Virtual Reality (VR), an understanding of the way humans utilize their skills is required. This thesis focuses on the topic of THWH interaction from the perspective of human abilities. Understanding human abilities draws on a method of human performance evaluation developed for analyzing human operation and interaction at a task level. This application of the methods developed in the first section of the paper addresses the recommendations made by the National Research Council's Committee on Virtual Reality Research and Development:

> Psychological Considerations
>
> RECOMMENDATION: The committee recommends that support for psychological studies be organized around the following objectives:
>
> (1) Development of a comprehensive, coherently organized review of theory and data on human performance characteristics...from the viewpoint of SE [synthetic environment] systems. [17]

The final aspect of this paper addresses the initial impetus for addressing the above issues. The United States military, notably the Army, is interested in using simulation technology to better and more safely train its personnel. The more advanced work in this area has been funded and directed by the Defense Advanced Research Projects Agency (DARPA) Advanced Biomedical Technology Program (ABMT). Aspects of this work involve the immersion of the 91B Field Medic (91BFM) and Dismounted Infantry (DI) into a simulated battlefield. Work on this topic has increased with the knowledge that simulation hardware and software have advanced the training that occur in the surgical and simulation training communities. This paper presents an analysis of the 91B Field Medic in terms of the THWH Classification developed herein, and compares this analysis to the equipment and techniques possible in the simulation field. "In addition to providing important relevant information to this community [VE researchers and medical simulation researchers], it would help delineate the further research that is required in this area to guide design of improved SE systems."[17] With this taxonomy, the simulation community is presented with the metrics that it needs to better understand the real world in order to implement VEs for optimal training.

II. BACKGROUND RESEARCH

A. INTRODUCTION

This chapter presents background for three areas of research: taxonomy and classification development; human computer and two-handed, whole-hand interaction; and the immersion of a 91B Field Medic into a virtual environment. Each of these areas is presented as a separate research area based on the historical separation between each of these fields.

B. INTERACTION AND TAXONOMY RESEARCH

> The world is full of single cases; single entities of animal of plant species, single case histories of disease, single books or socks.
>
> - Edwin A. Fleishman [23]

1. Introduction

A comprehensive and structured approach to virtual environment (VE) work is required to resolve the fact that the present state of human research in virtual environments exists as a collection of single cases. None of these single cases substantially increases our understanding of the overall problem of human interaction nor how future solutions might be devised in other than an ad hoc, intuition-driven fashion. There has been no concerted effort to study the techniques involved in the tasks performed by users in VEs in an attempt to analyze these tasks in terms of human performance. There has been no comprehensive analysis of the abilities required to perform tasks in a VE that are comparable to the performance in the real world.

Interestingly, the simple fact that a human is involved in the VE means that there must be some connection with how the user performs similar tasks in the real world. While some researcher would argue that VEs allow for the development of amazing experiences that do not exist in the real world, these same people are forgetting that humans perform optimally in the real world and bring this knowledge with them.

One approach that the world of engineering psychology and human performance evaluation has used to solve this problem is the development and applications of classifications and taxonomies of human performance.[23] The development of taxonomic systems for classifying tasks that people perform and the dimensions that are used to classify them has resulted in three aids to bridging the gap between basic research and application according the Fleishman. These taxonomies have:

> (1) eliminated redundant terms, (2) disclosed similarities and differences between 'operations' in the laboratory and the applied world as well as between various subject matter areas within research, and (3) alerted behavioral scientists to possible sources of variance that may contaminate or even negate their research findings in the operational setting. [23]

2. Classification & Taxonomies

Classification is the grouping and ordering of entities based on their relationships to one another; similarities and differences, observable or inferred properties.[23] The need for Classification is based on the ability to draw generalizations across events, an important goal of science, and for establishing and enhancing communication among scientists.[46] The history of classification and the development of classificatory systems is rooted in the development of primitive man and his associated civilizations.[54, 57]

The origins of the development of classification begins in the writings of the ancient Greeks. The early Greek theories of classification were developed by Plato and Aristotle and were predicated on the assumptions: (1) of a universal order existing in nature, (2) that this order, when discovered, would permit man the ability to slice nature into natural classes that would yield a permanent conceptual framework that consists of a hierarchy of genus, species, and subspecies moving downward from general to specific, (3) that the principle of differentiation that operates throughout the hierarchy is derived from the similarities of the attributes of components of the classified objects, and (4) that the properties concerned partake of the substantive nature of the units being classified and are not accidental.[57] Plato divided classificatory systems in those based on visible things or images and those based on ideas, while Aristotle delved further to produce a classification based on an objects essence. It is this work on the development of a classification system for the world, based on a taxonomy of objects' essence, that has led what is known today as Aristotelian thinking or logic.

The term taxonomy is used to mean the theoretical study of systematic classifications including their bases, principles, procedures, and rules. It is the science of how to classify and to identify. As stated earlier, the main goal of classification is to describe the structure and relationships of the constituent objects in regard to each other and to similar objects and to simplify these relationships so that general statements can be made about the groupings of the objects.[23] Other goals of classificatory systems are to "generate hypothesis", "achieve economy of memory", "facilitate communication", "ease the manipulation of observations", and "ease the retrieval of information".[23]

The development of taxonomies occurs typically in areas of heavy research where there is a strong desire to attack the overwhelming torrent of unorganized facts. The application of taxonomic theory to fields of this type makes it easier to be comprehensive in study, to better gauge the development of the field, and to contribute to the fields growth. The application of a taxonomic theory helps to refine areas of well-established findings, areas of confused, uncertain, or conflicting results, and neglected areas of study.

a. Human Abilities Requirements

One of the most well documented, modern taxonomy projects is the Taxonomy Project conducted at the behest of DARPA.[21, 22] The objective of the Taxonomy Project, in the whole, was to develop theoretically-based language systems (taxonomies) that, when merged with appropriate sets of decision logic and appropriate sets of quantitative data, might be used to improve predictions and generalizations about human performance.[23]

> [The Taxonomy Project] attempted to develop and evaluate systems for describing and classifying tasks to improve generalization of research results about human performance. [23]

It was the goal of the Taxonomy Project to progress toward a common task-descriptive language would help to integrate the human performance research literature and allow better communication between researchers and individuals who need to apply research to practical problems. This same goal underlies the work presented in this paper. "It is only recently that concerted efforts have been made to explore more intensively some of the issues and alternatives in taxonomic development in psychology and to proceed on an empirical basis in the evaluation of these alternatives."[23]

C. HUMAN COMPUTER INTERACTION

1. Overview

This thesis sets out to remedy, in part, a lack of communication across disciplines that would allow for comparison and analysis of similar research. With this in mind, it is crucial that all areas of research that may provide understanding for the hands problem be admitted as possible strong areas for background review. A listing of the areas reviewed for relevant papers is included below. Areas were not looked at for the number of published papers, or history of the field, or prestige of the researchers. Areas were reviewed for:

- the state of the research within that field in respect to the hands problem,
- the attempts by the field itself to generalize its findings within field and across fields, and
- the ability to actually generalize the findings in these fields to problems in the field of computer interaction and virtual environments.

The general fields of research that were reviewed comprise work in:

Aeronautical Engineering and Design	Computer Science (as a field)	Industrial Design	Engineering Psychology
Gesture Recognition	Human-Computer Interaction	Human Factors	Human Performance
Industrial Design	Mechanical Engineering	Robotics	Telerobotics
User Interface Design	Virtual Reality	Workforce Analysis	Workforce Modeling

This review was done over the course of a eighteen months while working on an applied version of the hands problem. As such, the review and removal of areas of research is itself not detailed in this thesis. As an analogy, this initial review is similar to someone who has never designed an car before asking what areas of research must be addressed to build a car, and then refined to the major areas that present the most gain to the design. Although Electrical Engineering, Human Factors, and Mechanical Engineering are all required (along with numerous other fields) for the design of a modern car, the field of Mechanical Engineering presents the most to offer for general knowledge in actually building a car. The design of the car should therefore focus foremost on the mechanical aspects and be knowledgeable enough to draw on the other fields as needed. The idea is that no one would question a person setting out to design a car why they aren't providing detailed explanation about the topics that they are not focusing on, but that may contribute to the overall end product. In the same way, there is justification in providing extensive background only in the areas that provided detailed studies or generalized knowledge applicable to the goal of the taxonomy.

One of the underlying motivations throughout the review of present literature was the development of a clear understanding of the areas of research covered, based on the abilities requirements developed later, and the areas that have been ignored. An obvious problem with much of the presently completed work is that it is difficult to move from any of the analysts' definitions of an ability to an applied state. Much of the reason for this research was to provide a more operational definition of two-handed interaction that can be used reliably by practitioners to estimate the ability requirements of a new task.

2. Interface Design

The development of interfaces for computers has evolved in conjunction with the evolution of the computer processor. In the late 1990s, the computer interface revolves around the internet browser, based in large part on the graphical user interface (GUI) that was both a launching pad and driving idea behind the browser. The use of the GUI was the progression of the computer interface based on the computer's new abilities in the seventies and early eighties. This work focused on the ability to display what was considered the textual standard of the time, moveable type printing. The use of movable type brought about a revolution in how books were published hundreds of years ago, and the seventies and eighties led to the creation of new computing interaction model based on the page and the limited interaction devices that were being connected to the computer.

The keyboard had been a standard interface device for the personal computer through the early-eighties. The introduction of the GUI interface presented the need for something more that key commands to move around the graphical environment. The GUI spawned the mouse, which further drove what could be done in the GUI. Both the GUI and the mouse were swept along by the creation of new uses for systems based on these devices.

With the nineties coming to and end, we are seeing the introduction of a proliferation of new uses for computers based on advancements in graphics, sensors[56], wireless networking, portable computing, wearable computers, et al. And yet most computers are still limited by the keyboard and the mouse. What were once seen as revolutionary interaction devices spurring the use of computers in new and interesting ways, have now become a balland-chain for the computer industry. Interaction with computers is straining to move forward, but the physical constraints of the interaction devices is holding it back.

The future holds a number of new interaction devices and methods, most of which will not be "discovered" until some breakthrough application drives the need. In the interim, interaction specialists can attempt to push the development of advanced interfaces based on the desire to allow the human to become more conversant with the computer. The user interacts with the real world throughout their life in what most people would consider to be the penultimate form of human interaction. To allow richer dialogue to occur between the user and the computer, one avenue to attempt development in is to take the interactions humans hold with the world and attempt to convey the same information to the computer.

Some of the ways in which humans interact with the real world (and by relation, other people in the real world), is through the use of our fives senses.[1] To varying degrees and in various situations, each of the five sense provides an amazing amount of information about us and allows us to collect this information from others. Sight, smell, sound, taste, and touch. Simplified? Amazingly so. But this simplification allows for people to more easily grasp the complex interactions and communications that can occur with people. This paper focuses on one sense, touch, that is ignored by today's computers. Touch is also ignored by most humans during their interaction with computers, save for the simple sense of touch-typing.

3. Computer Science

The area of Computer Science (CS) presents a great deal of literature, which will be discussed in depth later in this chapter, dealing with handed input. The work here is split between symbolic and non-symbolic information being obtained from the hands. The use of the hands to transfer symbolic information is considered based on the fact that the focus of related studies is often the use of the hands to convey symbolic information that is related to the non-symbolic information that is transferred in the real world. This is in sharp contrast to the Gesture Recognition work where the focus is on how well a computer system can analyze the symbols displayed. Some of the work in CS has presented the study of symbolic gestures in non-everyday tasks to understand the use of non-symbolic gestures in everyday tasks. Examples of everyday tasks are grasping a pencil or holding a glass. Non-everyday tasks are moving a mouse to provide information to a computer. In both the symbolic and the non-symbolic research, the focus on the human was considered for this thesis.

4. Human Factors & Human Performance

The areas of Human Factors and Human Performance were merged due to the crossovers implicit in the researchers and the literature.[1] The vast amount of literature in these two fields related to the use of hands (and two hands

1. Throughout the rest of this thesis, the term Human Performance (HP) will be used to encompass both fields, unless otherwise stated.

in particular) was done by the same people under the auspices of both fields. Neither focus of the related research in the two fields presented differing messages or results. The classification of research on hands was separated into either one field or the other based on non-scientific reasons; the department that the researcher was from, the degrees held by the researcher, or the audience that the work was being presented to. Although the motives behind the differences area true, they do not affect the work that was done nor the results and conclusions that can be drawn.

As a note, one of the reasons that the fields of HF and HP present a more refined and simplified set of messages is that these fields have existed as disciplines for a longer period of time than the other topic areas under study. Both of these fields have evolved as refinements from specialized work in two other fields that possess histories of classification of studies; Mechanical Engineering and Engineering Psychology.

5. Gesture Recognition

The area of Gesture Recognition fits all of the criteria; it has provided extensive literature on the use of one or two hands in its work, the researchers are attempting to create general methods, the work being done is cutting edge, and there are a large number of very strong researchers with developed goals working on various aspects of the problems. But after reviewing the research it was found that the work focuses on an different aspect of two handed input. The work in gesture recognition attempts to use the hands to convey symbolic information to a computer, based on the previous use of hands by humans to convey symbolic information to each other. Although the use of hands was implicit in the studies reviewed (since the focus was on handed studies), the use of the hands for interaction was limited to the delivery of gestures. The Gesture Recognition problem is not one of how a human displays a gesture, but how well the interpreting system can understand the symbolic intent of the gesture. The focus of the majority of this research is not on the human but on the interpreting system. This is not to say that the work in Gesture Recognition has no interesting lessons for the understanding of handed input, simply that the results and conclusions presented are not focused on the human. This is a strong argument for removal from a study that hopes to gather the state of the art knowledge on human focused studies.

6. The Field of Human-Computer Interaction Research

In the field of computer research and design this area of study is commonly referred to as human-computer interaction (HCI) or user interface design (UID). Advanced research with computers has led to the creation of virtual reality environments using real-time, three-dimensional graphics and the immersion of the user into the operant environment.[2] HCI practitioners and researchers are applying their methods to VR and are beginning to discover a number of new areas of human studies which have not required strong understanding before now. Each of the five senses is being studied in an attempt to provide deeper understandings of how humans work to in turn allow VR systems to more

2. The term immersion is not well defined within the field of VR research. Throughout this paper the use of immersion refers to the user's impression of interacting with the computer environment. The term physical immersion is used when the idea being conveyed relates to physical device encumbrances placed on the user.

fully complement the humans.[17]

The focus on developing a more extensive human model has taxed the present limits of comprehensive research methods. The field of HCI is a young field, existing only since the introduction of the computer, which is still developing its tools and methods.[56] VR is a topic that ideally requires a complete and detailed understanding of the human animal.[17] Vast amounts of data is collected and large numbers of studies have been performed in VR environments in order to discover the detailed human. Based on present methods, this work is best seen as separate and distinct with few connections to previous research. In addition, this work is unable to provide general understanding for practitioners seeking to deliver this research to the user.[17] There have been few comprehensive attempts within the field of VR to gather and classify the data and studies with the goal of providing general rules or methods. This paper provides the first attempt at developing a comprehensive analysis and presentation for the area of two-handed, whole-hand interaction. This paper also presents a methodology developed in another field of engineering psychology that can be used by HCI practitioners to begin to address numerous areas of research and development.

D. HANDED RESEARCH

> There has been little work to examine the full potential of the hand as an input device. - David Joel Sturman [62]

1. Introduction

Hands have been the dominant input method for computers throughout their short existence. Switches, punch cards, keyboard, and mice have all relied on the use of human hands for communication by the user with the computer. This is not by chance, but based on the dominance of hand usage by humans in the everyday world.[46] As technology continues to advance, various aspects of the hand are being further researched.

Hands have been used in computer interaction to allow the user to operate on objects or tools designed for the computer. Much of the research in handed interaction has continued to focus on this path; understand the hands in the context of specialized computer input devices. This thinking shows up in much of the work presented in this section, and is exemplified in the following comment:

> In three-dimensional immersive environments, however, two-handed input becomes even more important. as individuals use both gestures and postures to indicate complex relationships between objects and operations in space. [17]

One area of handed interaction that has received little study is how humans use their hands to interact with the world around them.

2. Two-handed Research

Before attempting to explain the work that has been done in interface study and design relating to the use of the hands, it is useful to look at some of the early interface studies that were done and the ideas that drove them.

Interface testing has existed in print and as a discipline from the beginning of the industrial revolution, but was not focused on the issues that are looked at today. From the beginning, the study of people was most often performed in order to build more efficient assembly lines, of which humans were an important, though undifferentiated part.[63, 64, 65] This study of humans as machines, though derogatory in today terms, was the first real attempt at studying and modeling human performance and operation. This model of humans still holds in many industries today, but is slowly shifting to a more human-centric view.[65]

The advent of the modern human-computer study, with the human as a central focus and not simply as a part, began sometime in the sixties and seventies in the United States, although there are no definitive histories on this work at this time. Much of the work was completed at centers like the Xerox Palo Alto Research Center (PARC) in California and was done without the need to build an amazing product based on the research in the short-term. Other pieces of this problem were being completed at associated research centers and universities, most often under the auspices of the U.S. DoD.[66] The most well known of the early computer-human interaction studies is the work on Fitts' Law as applied to the use of computer mice and on the typing skills on computers presented by PARC secretaries.[9]

This work continued into the late seventies and early eighties at companies centered in the Silicon Valley area of California: Atari Research Labs, Apple Computer, Inc., Hewlett Packard. It was during this time that the field of HCI began to coalesce and demand attention both from the historical design fields and from the computer designers. This field of research is now an accepted part of the computer community and is present in most companies and products, though not to the degree that it should be. It is from this burgeoning field that the use of the human hand, the use of two hands, and the use of two-handed, full-hand interaction has emerged.

3. Yves Guiard

The underpinnings of much of the two-handed research being done at various institutions at the present is predicated on that of what Yves Guiard has termed the kinematic chain model.[25] Guiard's theories focus on movement, perception, and bimanual action — the use of two hands to operate in a cooperative action. His work attempts to provide a basic scientific understanding for the use of two hands in a cooperative fashion to solve a variety of everyday tasks. Guiard's research is based on the theory that the majority of human manipulative tasks are bimanual acts. He believes that the bimanual is more natural that the unimanual and attempts to show this extensively in his book.[25] He furthers this work through application of the dominant/non-dominant hand theory.

Guiard's work must be respected for the attempt to provide a general, theoretical framework for classifying the use of two-hands in manipulation. The Kinematic Chain Model provides a general model of skilled asymmetric bimanual action, where the kinematic chain represents the concept of a serial linking of abstracted motor skills. This model is well understood by anyone who has worked with robotic models.[14] The kinematic chain is based upon the concept of links with a proximal and distal point. The chain represents the fact that the distal point is dependent on the movement and action of the proximal point through the static action of the link. Guiard extends this well understood concept to the idea of the preferred (dominant) and non-preferred (non-dominant) hand. The idea of a dominant and non-dominant hand is hand is easiest understood in observing right- and left-handed user interaction. Using this theory and observations, Guiard has proposed three high-level principles for defining the asymmetry of human bimanual gestures:

> Motion of the preferred hand typically finds its spatial references in the results of the motion of the non-preferred hand.
>
> The preferred and non-preferred hands are involved in asymmetric temporal-spatial scales of motion.
>
> The contribution of the non-preferred hand starts earlier than that of the preferred.

To elucidate the three principles:

- The non-preferred hand tends to large, sweeping motions while the preferred hand operates in a frame of reference defined by the non-preferred hand.

  The preferred hand performs small, precision motions in contrast to the large, sweeping motion on the non-preferred hand.

  The non-preferred hand initiates the action. [25]

Guiard has used these three principles, a number of bimanual experiments, and extended thinking on the bimanual problem, to provide a taxonomy of bimanual actions. The three principles provide the foundation for his understanding of Bimanual Asymmetric manipulations. Bimanual Symmetric motions are not governed by these principles according the Guiard.[25] Additionally, these principles do not account for the symbolic gestures or non-manipulative gestures that are also based on two-hands, and which make up a seemingly large percentage of humans daily hand action. Using hands to illustrate speech is a common example of this as is the use of gestures to convey symbolic information.

While his work provides a systematic approach to bimanual action problems, it does not attempt to include but a subset of the full-range of actions that are possible. This model does not present a general model which could be extended to encompass all classes of two-handed input.

4. University of Toronto

Some of the earliest work on the use of hands as an interaction device is that of William Buxton with the University of Toronto. Much of the work presented here is based on Guiard's Kinematic Chain model. Buxton's work, as well as that of his students and collaborators, Kabbash, Kurtenbach, Leganchuk, MacKenzie, has focused on the optimization of various types of tasks through the use of two hands.[6, 8, 18, 34, 35, 41, 43, 44] In most cases, the experiments run and the problems under study relate the optimization that can occur when bimanual versions of normally unimanual tasks are built. Much of the research is predicated on the belief that two-handed input can yield significant performance gains.

Buxton attempted to address the human factors issues related to different hand input devices in his *Taxonomy of Input Devices*. Buxton places the input devices into categories based on the properties that each device senses, such as position or motion, and on the degrees of freedom.[5] This work was extended to include the continuous and discrete properties of hand input devices by Card, Mackinlay, and Robertson.[9] Buxton further extended this line of work by presenting a model that encompasses the hybrid discrete and continuous properties of many of the hand input devices. Sturman's analysis of all of this work is that "...the majority of [the studies] are too context dependent to be generally useful."[62] At the same time, this work presents much basis for what most people feel is going to be the dominant for of two-handed, full-hand input; non-device constrained, three-dimensional interaction. "Relying solely on extensions of our experience with two dimensions would not provide adequate solution approaches to three-dimensional interaction needs,...."[17]

Kurtenbach and Buxton present a two-handed interface that does not allow for actual two-handed, whole-hand interaction in [41]. It presents another GUI paradigm which uses non-standard UI technologies, multi-sensor tablets, toolglasses, transparency in the interface, and marking menus. The hands are used, one on each tablet mouse, a device used often in CAD design that usually has numerous buttons (5+) and is often used as an absolute positioning device.

Fitzmaurice and Buxton present the concept of specialized two-dimensional input to control three-dimensional data with the use of space-multiplexing rather than what they consider the standard time-multiplexing interface, the mouse, in [19]. In the space-multiplexed interface, each function controlled is given its own physical object to control its aspects, while time-multiplexing is represented by the mouse due its usage, over time, to control all the different aspects of all the objects using the same physical object. Armed with data from experimentation, they posit that the specialized devices used in the space-multiplexed interface provide enhanced visual and tactile feedback missing in the mouse that serve as cues as to the functions of the associated tool as well as providing better manipulation abilities.

Shumin Zhai's manipulation work at University of Toronto and has since moved on to the IBM Almaden Research Center. Zhai's work focused extensively on the use of 6-DOF controllers for control and manipulation and computer and VE systems.[67, 68, 69] Although this work does not directly address whole-hand manipulation, it is some of the strongest work to come out of Buxton's research group.

Whereas much of the work at Toronto is based on student research and is not advanced in a goal-oriented manner once the students graduate, the work of Chris Shaw, along with Mark Green, is continuing and presents what could be one of the stronger programs in the long-term.[58, 59, 60] The work presented by Shaw is focused on the use of two-hands in the design of objects.

5. Kevin Hinckley

The most recent work on two-handed, whole-hand interaction comes from Kevin Hinckley while at the University of Virginia, now with Microsoft Research. His work, spread over a number of years, focused on various aspects of two-handed interaction in real world problems.[27, 28, 29, 30, 31, 32]

The majority of his work, experiments and the lessons, is gathered in his doctoral dissertation.[29] This work covers the range of topics which are covered in his previous papers; haptics, spatial input, manipulation, bimanual coordination and frame of reference.

Hinckley states that his work is different from all previous two-handed research in user interface literature "along several dimensions."[30] He states that (1) he has applied virtual manipulation to develop a new and novel interface for volume visualization in the area of neurosurgical visualization, (2) his work was driven by the real-world needs of an actual user, neurosurgeons, instead of simply being driven by technology, and (3) his work has combined aspects of the systems-building approach and the purely experimental approach to offer and discussion which "is both timely and relevant to design."[28, 29, 30] His work presents the broadest approach to the problem of two-handed interaction, in looking at all aspects in a cursory fashion he has provided the readers with a good sense of the issues that are faced in the development of a real world system and how he approached these issues.

6. David Joel Sturman

David Sturman developed a taxonomy for whole-hand input for his Ph.D. thesis in the Media Arts & Sciences program at the Massachusettes Institute of Technology.[62] His work focused on presenting the use of a single, whole hand as an independent study, without reference to specific application, three-space environment, or interface device. As his work provides a first step for the development of the two-handed taxonomy and for an structured approach to this problem, his work is presented is detail below.

a. Whole-hand Input

> [T]o have some basis from which to be able to describe, discuss, contrast, and evaluate different tasks and interfaces, there has been a strong effort in the classification of user interface devices and interface methods, and in the development of task assessment. Given these two sides of the problem, the need for common bases of descriptions and evaluation, and the need for iterative design, this dissertation concentrates on the organization of ideas and tools for the description, evaluation, and design of whole-hand interfaces. [4, 8, 9, 55, 62]

Sturman's focus on whole hand input revolves around three issues; the appropriate use of whole-hand input, the appropriate control design, and the appropriate device. The first issue, appropriate use of whole hand input is focused on defining when and why whole-hand input should be considered for use in an application. The second, appropriate control design, focuses on the best method of using whole-hand input in an application, assuming that the use of the hand was deemed appropriate. The third, appropriate device, looks at the application's data input needs and refines which device should be used to capture the whole-hand input.

Sturman points out a variety of other methods that have been promoted in the analysis of whole-hand input. His review leads him to conclude that the work to that point focused on "low-level psychological capability, task performance, or the cognitive basis of hand function."[62] Previous review by Lynnette Jones places hand function assessment techniques into three other areas, "muscle and joint function and dysfunction, tactile sensibility, and functional or task-oriented capability."[33] Some of the other areas of hand function and behavior analysis he reviewed does well at providing explanation, but it his opinion that these explanations do not allow for evaluation or prediction of whole-hand usage across applications.[13, 36, 42]

"Much of the existing work examines the use of specific whole-hand input devices in the context of specific applications."[62] In a vein very similar to the thoughts behind this thesis, Sturman's dissertation "has no dominant precedent in any one field and borrows from several domains of study."[62]

The crux of Sturman's dissertation is his Design Method for Whole-hand input. This design method seeks to present a disciplined approach for addressing the issue of whole hand input for any application or task, much the same way as this thesis seeks to develop a similar approach for two-handed interaction. This design method is broken into several stages. None of the format of the design methodology is in itself radical. Instead, the design methodology is based on the proven work of designers.

b. Sturman's Design Method for Whole-hand Input

The first step in this design method is Appropriateness. In this stage, the researcher or designer chooses the appropriateness of the use of whole-hand input in the application under development. The designer asks as series of questions about the application which are based on Sturman's main features of whole-hand input: naturalness, adaptability, and dexterity. This is an important step that is often ignored by designers; choosing whether an advanced input technique is even appropriate for usage in a new application.

c. Evaluation Guide

The next stage is to break the application apart into task primitives for use with an Evaluation Guide. One of the key differences between his approach and that of this thesis is in Sturman's Evaluation Guide. At this stage in his methodology, the application under study is broken down into task primitives. "Each of these task primitives are analyzed with specific measures that quantify it in ways that can be related to analogous measures of hand actions."[62] The examples of task primitives that are presented comprise some of the following: unbolting an access hatch, removing the hatch, removing a defective module, storing the module away, unpacking the new module, inserting it into place, and replacing and rebolting the access hatch. This level of task analysis and definition is best described by either the "synthetic work approach" or the Job Element Method of human performance evaluation.[2, 10, 23, 49, 50, 51, 52, 53]

The designer chooses the whole-hand input aspects that are present in the application based on previous work by others, previous experience, or observation of how people use their hands in the actual or related applications. The designer compares the evaluation guide's measures to the hand actions; task primitives to hand actions. In this method, if the hand actions do not correlate with the task primitive requirements the hand actions can be refined or redefined based on deficiencies revealed in the analysis. The next stage is Device Selection. A device is chosen based on the correlation between device capabilities and the tasks and whole-hand input methods defined.The final stage is to prototype the device and input method in a simulation of or in the actual application. If further refinement is desired then the designer can return to most any stage in the methodology and continue.

7. Touch Research

The ability of humans to use touch to interact with the world has always been an untapped skill. People are not often placed in a situation where they actively think about their ability to touch an object and how that enhances or detracts from their experience or interaction with an object. With computers, the use of touch is a new experience and one that few people in the HCI field possess. At the same time, the use of touch by humans to allow for further exploration and manipulation manifests itself in a variety of human interactions, one of the most obvious being the use of hands. Humans use their hands to explore the world and to continually manipulate the world around them. Furthermore, people operate their hands with full use of the numerous degrees-of-freedom they possess, with the fact that they have two opposing hands that can both operate independently and together, and with the ability to use the fingers (based on dof) to interact in ways impossible with any other human appendage. And with the huge amount of implicit information gained from the use of touch throughout the hand. It is the use of hands and all the myriad related issues that is the sole focus of this thesis and which will be explained in depth throughout the rest of this paper.

The task level analysis of two-handed interaction may be different from some of the previous approaches seen in the world of haptic literature. Due in part to this fact, only a few aspects of haptic work are discussed. The problems being addressed by the haptics community is well beyond anything that is being reviewed in this thesis due in large part to the fact that haptic research has focused extensively on the physical aspects of touch that are needed in order to duplicate the sensation and perception of human touch. Instead, the focus of this work on the human abilities level, attempting to match the level of analysis presented in the Human Abilities Definitions of the Taxonomy Project. This choice is based on the extensive support for the approach presented in the Taxonomy Project and subsequent projects, as well as the requirements outlined for the virtual environments research community:

> A primary classification of haptic interactions with real environments or VEs that affects interface design can be summarized as follows: (1) free motion, in which no physical contact is made with objects in the environment; (2) contact involving unbalanced resultant forces, such as pressing an object with a finger pad; (3) contact involving self-equilibrating forces, such as squeezing an object in a pinch grasp. Depending on the tasks for which a haptic interface is designed, some or all

> of these elements will have to be adequately simulated by the interface....Consequently, the interfaces can be classified according to whether they are force-reflecting or not, as well as by what types of motions and contact forces they are capable of simulating.[17]

The approach defined in [17], and the approach that is taken in this thesis, is not at the perception level but at the human abilities level. "Compared with the visual and auditory domains, the capabilities of haptic devices and our understanding of human haptics are quite limited." [17]

Evaluation of haptic interface is crucial to judge their effectiveness and to isolate aspects that need improvement. However, such evaluations performed in the context of teleoperation have been so task-specific that it has been impossible to derive useful generalizations and to form effective theoretical models based on these generalizations. There is a strong need to specify a set of elementary manual tasks (basic tasks) that can be used to evaluate and compare the manual capabilities of a given system (human, robotic, VE) efficiently. Ideally, this set of basic tasks should be such that (1) knowledge of performance on these tasks enables one to predict performance on all tasks of interest and (2) it is the minimal set of tasks (in terms of time consumed to measure performance on all tasks in the set) that has this predictive power.[17]

E. DARPA ABMT 91B FIELD MEDIC INITIATIVE

The development of this taxonomy was driven by my work on a project funded by the United States Defense Research Projects Agency Advanced Biomedical Training program (DARPA ABMT). The task which was apportioned to me was based on a demonstration that was funded to include work by The Naval Postgraduate School's NPS-NET Research Group, the University of Pennsylvania's JACK group, and the Sandia National Lab's Virtual Reality Group. This work was intended to complement existing work being completed at other companies and to provide a demonstration platform for the training of military 91B Medics in a virtual environment. At the point this research was concluded (early 1997), the majority of research under the ABMT program had been directed toward issues revolving around telesurgery and surgical training. The intention of the DARPA program manager, Colonel Richard Satava, M.D., was to complement this work and repeat the success seen with surgical trainers in the area of 91B Medic training.

NPS joined this project once the first demo had already been completed, in which there was no human interaction other than in starting the demo and allowing medic avatars to operate in a military scenario environment (Distributed Interactive Simulation or DIS). No human interaction had been reviewed at this time, independent of the fact that a majority of the difference between surgical simulation and possible medic simulation was based in the differences in the ways that these two groups operate.

NPS was tasked with integrating the medic simulation into the large-scale, networked, virtual environment. In order to do this, a strong understanding of the types of data that needed to be sent over the network was required. This understanding was meant to optimize the data's transmission and to fit this data into the format specified by the simulations; DIS. In attempting to gather this information, it was discovered that the group tasked to perform the Medic interaction study and implement the user interface had not started this task and due to funding and staffing issues did not expect to approach this issue: they did not provide a possible future date for this work to be started or completed.

Being stationed at a military base, with an attachment of Medic personnel at a close by related base, presented the opportunity to begin a Medic study and to attempt to provide the data on Medic interaction that was required. The military had already defined the Medic training program in terms of real world tasks, leading to the belief that a quick understanding of the human requirements, and thereby the human data generated, to perform the tasks would be forthcoming. In review of this literature, it was discovered that there was no present understanding of the full panoply of human abilities in the virtual environment which could be applied to these real tasks.

Upon further review, the work done by Fleishman and associates [23] presented a validated set of real world human abilities in a manner that allowed for application to the Medic tasks. In order to fully cover the work that was being attempted, a virtual environment training system for the Medics, the assumptions that were implicit in the Fleishman work had to be discovered and removed if counter to the usage of a VE. After review, this was found to relate most heavily to haptic issues. With the addition of the haptic tasks, one of the first steps is an application of the taxonomy to the Medic real world tasks, defined in the Soldier's Manual CMF 91 General Medical Tasks.[61]

At this time, the Col. Satava has finished his appointment as ABMT program manager and left DARPA. The program is presently under study, while the Medic study is not scheduled for further funding, at either NPS or related sites. With this in mind, the actual implementation of the information and knowledge gathered in this study into a networked virtual environment is not planned.

F. SUMMARY

As Hinckley points out, "[o]ne thing that stands out in a review of the user interface literature is how few systems have supported two-handed interaction."[30] One of the other things that could be stated is that of all the two-handed interaction literature, none of the studies presently published has approached the problem in a non-device specific, non-application specific, or non-user specific manner. Although there are a number of strong papers and findings among the literature presented here, none of them provides a general approach needed in order to advance the broad understanding of two-handed interaction.

III. CLASSIFICATION AND TAXONOMY DEVELOPMENT

A. CLASSIFICATIONS AND TAXONOMIES

As described by Fleishman, the majority of the taxonomies in the virtual environment literature are Linnaean taxonomies.[16, 24, 63] These taxonomies attempt to classify entities and groups in terms of their "essence." There are no set rules or procedures for how an entity is classified. This method involves significant subjective judgement as to the "essence" of an entity or group of entities. Furthermore, the context in which an entity is to be classified has everything to do with the language used to describe it. This is a recurring issue in VE literature. An engineer might describe a glove device in terms of its components (fiber optics, stress sensors, etc.) while a psychologist might describe it in terms of the tasks for which it can be used (pointing, grasping, etc.). What is needed is a taxonomic methodology that maintains consistency and repeatability in an objective manner; across researchers, organizations, studies, and systems. Such a method is called a Numerical taxonomy and is the basis for the classification is presented in this paper.[16]

The distinction between a taxonomy and a classification is often blurred in present VE literature. The methods underlying the development and extensions of classifications is called taxonomy research. The process and method used in the development, and later in the extension, of lists of grouped knowledge is a taxonomy. One of the initial results of a taxonomy is the production of a classification, or listing, of the knowledge being studied.

While a classification is useful to practitioners and researchers in allowing for the grouping of knowledge, it is limited in usefulness without an underlying taxonomy. The taxonomy directs involved parties in a more detailed understanding of the assumptions inherent in the classification. In addition, the taxonomy is crucial in allowing researchers to extend or enhance the classification based on new knowledge or research. Most importantly, a classification is heuristic; it guides future investigations by stating hypotheses. The delivery of an underlying taxonomy for any VE classification being developed is crucial in a field at this young age. The terminology presented above is well understood in the field of human performance and can be stated as follows:

> A taxonomy is the theoretical study of systematic classifications including their bases, principles, procedures, and rules. The science of how to classify.
>
> A classificatory system is the end result of the process of classification, generally, a set of categories.
>
> A classification is the ordering or arrangement of entities into groups or sets on the basis of their relationships, based on observable or inferred properties.[24]

Taxonomy research and the development and application of classifications typically occurs in areas of heavy research where there is a strong desire on the part of researchers, and more importantly practitioners, to address the growing development of unorganized facts. The application of classification development to fields of advanced research allows the fields to more rapidly develop by enhancing communication using a common language. The field becomes more comprehensive in nature, allowing participants and observers to better judge the present state of the field, to judge development that occurs, and to use this knowledge to drive their own contributions. Classifications allow participants to better communicate the results of studies, to resolve confusion that exists between existing research institutions and programs, and to point out areas of neglected study. These assumptions underlie the work presented in this paper.

Classifications and taxonomies are not an end in themselves; they tools can be viewed as tools that provide the increased ability to interpret, predict, or control some facet of performance.[21] This goal is accomplished through the understanding of the information which is classified, and the differences in variables supported by each of the terms in the classification. The creation of classifications for use as tools begs the question as to whether the taxonomy which is created will be specific to one application or user area or whether it is "designed from its inception to be general."[24] The taxonomies existent in the literature presented in Chapter II, Background Research and in the Bibliography of Other Works, are all application or user area specific, regardless of the stated intentions to be general. This statement does not hold for Sturman's dissertation.

At the same time, classifications and taxonomies do not show researchers where to find the next set of answers. What they do is help the researcher to understand the knowledge that they possess. By extension, the researcher is then able to describe areas of knowledge or research that are not complete. This enunciation of a taxonomy of areas or subareas of human performance provides both scientific-theoretical and applied-practical benefits. A list of possible benefits are presented in detail in Appendix D, Benefits of Taxonomy Research, and are presented in short below.

Scientific-Theoretical Benefits

- Conducting literature reviews
- Establishing better bases for conducting and reporting research studies to facilitate their comparison
- Standardizing laboratory methods for studying human performance
- Generalizing research to new tasks
- Exposing gaps in knowledge
- Assisting in theory development

Applied-Practical Benefits

- Job definition and job analysis
- Human-machine system design
- Personnel selection, placement, and human resource planning
- Training
- Performance measurement and enhancement
- Development of retrieval systems and databases [24]

1. Human Abilities Requirements

With this general understanding of classifications and their uses, this paper focuses on one well developed taxonomy of human classification, that of Human Abilities Requirements. Edwin J. Fleishman and his associates have been developing this methodology and classification of human abilities since the mid-1960s. This work was initially funded by DARPA in order to provide a classification of human abilities for use by the military for training and for better job placement of skilled personnel. This taxonomy has been documented in numerous articles and books, while the resulting classification has continued its refinement and is presently codified in the Fleishman - Job Analysis Survey (F-JAS).[21, 22, 23, 24]

An example of a human ability is Static Strength: a human's ability to use continuous muscle force to lift, push, pull, or carry objects.[22] The human abilities defined by Fleishman are presently grouped into four metaclasses; cognitive, psychomotor, physical, and sensory/perceptual. Work is being undertaken by Fleishman and associates to define human abilities for two other metaclasses; interactive/social and knowledge/skills. The belief is that any number of human abilities can be used to describe the way that a human solves a problem.

Each of the human abilities defined in F-JAS (and by extension, this classification) is presented with a representative name and definition text. The definition allows for the analysis of human tasks using an absence/presence evaluation and reporting scheme. Absence/presence evaluation is simply the use of a standard definition to decide whether or not the idea or task presented in the definition is absent or present in the thing being observed. In addition to the definition, each of the human abilities is also represented by a seven point scale using a behaviorally anchored rating technique that anchors both the high and low ends of the scale with additional definitions and task examples.[22,24] The use of scaled analysis allows the application of the taxonomy to move from being largely qualitative to quantitative. Each of the tasks can be further analyzed, beyond absence/presence, using the scales to derive ordinal ratings. The scales for abilities included in F-JAS can be found in [24]. The scales developed or extended in reviewing the VE human can be found in in this paper and in publicly available reports from the NPSNET Research Group. These new abilities' scales are presently being reviewed for completeness against a large number of human tasks.

Fleishman's work provides a basis for the understanding and development of a new view of humans in VEs. Although a full presentation of F-JAS and the taxonomy of Human Abilities Requirements would be helpful for the reader's continued reading of this paper, the volume of information underlying this work makes this impossible. A more comprehensive explanation of all aspects of the work completed by Fleishman, as well as our extensions and applications, can be found online at our institution; the authors point readers to this site, or to opening a dialogue if there is interest in a stronger understanding of this work and its application.

B. THE NEED FOR CLASSIFICATIONS IN VIRTUAL ENVIRONMENTS

The critical problem that this system of classification addresses is that researchers and practitioners in virtual environments do not speak the same language. The relatively recent engineering breakthroughs that have enabled the creation of VEs have brought together an eclectic group of professionals, each applying their field's methods to problems associated with humans in computer-generated, synthetic spaces. In attempting to address these issues, these same people are beginning to discover that the study of humans in VEs requires a broad understanding and application of multiple methods of human studies which, until now, have only been studied within the context of real world tasks.

Human performance research in VEs is being explored by professionals from myriad fields of research: human factors, behavioral and cognitive psychology, computer science, industrial engineering, and biomechanics, to name a few. Each of these disciplines has its own methods of addressing issues related to human performance. Each field's supporting research on humans in VEs has brought with it expertise that was developed over years of study, as well as its own terminology, methods, histories, and acknowledged leaders.

Vast amounts of data have been collected from a large number of studies in an attempt to understand various aspects of human performance in VEs. However, it is often difficult, if not impossible, for new research to build on previous research because there is no common ground on which to construct a useful dialogue. Consequently, the research being performed is not providing a general understanding of the issues allowing the development of better VE systems by practitioners. In situations such as this, a classification help in framing a problem area and providing that common ground on which to discuss its implications.

> The need for classification is based on the ability to generalize across events, an important goal of science, and for establishing and enhancing communication among scientists.[47]

The development of uniform, transferable concepts, definitions, and models of user behavior is all too uncommon in areas of advanced research. There is often little time for retrospection in bleeding-edge research; even this realization is often not acknowledged. This lack of general methods and rules hinders the possible impact of the present research on future development and products.

Before going further, it is important to state one assumption of the VEs discussed throughout the rest of this thesis. VEs are a class of computer simulation in which a human plays an integral role. If a human is not in the real-time loop of a VE, then the system being discussed in not a VE, but simply a set of algorithms. This distinction is not meant to slander pure computer simulations, but to help better define the requirement of having a human involved in any discussion of a VE.

With this assumption, the heart of any VE system is the tasks that a user can and will perform in that system.

The performance characteristics of these tasks are clearly not identical to their real world counterparts using today's technology. What is needed is a way to cross barriers from the real world to the virtual world by extending taxonomic methods of human performance to include VEs. The universal objective of building effective VE systems is to capture the full extent of human skills and facilitate their usage. This requires that a VE system must provide a comprehensive model of human performance in order to be compatible with human capacities and limitations.

The above argument is true for VE training systems, which seek to duplicate the real world, and for non-realistic or abstract VEs, which seek to explore experiences not presently possible in the real world. As stated before, involving the human in either type of system automatically requires an acceptance of human lessons and skills developed in the real world. While it would be an interesting theoretical problem to build a VE that utilizes absolutely no knowledge or skills developed in the real world, the "perfectly abstract" VE, the problem with such an environment would be that a human couldn't use it. If the human is to be involved, then the interaction techniques must be based on something the user is familiar with, and consequently, natural human abilities. This is not to suggest that VE interfaces must always mimic the real world to the highest degree. Simply, user performance in VEs is based on expectations and abilities developed and grounded in the physical world.

The application of classifications and taxonomies is not new to virtual environment research and human-computer interaction, but has not been applied yet in a broad manner to the full array of problems being addressed. In most VE human interaction, there is presently no taxonomy or classification of human abilities. As people attempt to answer new questions at various research centers and institutions throughout the world, this approach can help generalize, communicate, and apply the research findings outside of the applications and situations in which the research was developed.

1. Qualitative and Quantitative Classification

"As a minimum requirement, the descriptors [definitions] employed in the differentiation and classification of tasks must permit nominal scaling."[24] An expert using the taxonomy must me able, at a minimum, to decide whether the definition does or does not apply to the task under study; presence or absence. The ability to apply definitions to tasks is further defined according to (1) whether the definition contains one or two attributes which must be present or non-existent in a task in order for the definition to be applied or (2) by applying the definition a based on the overall pattern of the definition; no single attribute decides inclusion or exclusion. In either case, the qualification of the tasks is based on the ability of experts acting as judges to make the decision as to whether skills in the definition are absent or present in the task.

Using a nominally based classification directs the researchers to base similarity on the number of common attributes presented by definition. As is obvious, this approach fails when the question of differing levels of abilities is broached, in particular when the differing levels are not only present but also greatly affect what constitutes similarity. As pointed out in the <u>Taxonomies of Human Performance</u> there is also an issue of sampling error in regards to the decision of presence or absence by the judges. The importance of sampling error is based further on the question of how the resulting data is meant to be used.[24] If the data is simply to be used as an index, then the absolute presence or absence of definition attributes is acceptable. But if the goal is to allow for manipulation of task parameters and, as an example, prediction of learning, then the issue of degree becomes important. The addition of degree to the argument presents the analysis as quantitative, in varying degrees. The amount of difference in describing abilities is now possible and permits use of ratio, interval, or ordinal scales in discussions. As a note, the data developed in this thesis is at most ordinal.

This thesis is based in large part on an already quantified set of description derived from the Taxonomy Project and codified as the MARS or F-JAS. Excluding this fact, the addition of new assumptions (or removal, depending on how the question is stated) presents the need for new definitions revolving about the question of haptic ability. These new definitions, coupled with the already refined definitions, presents a new classification for study. As such, it is important to understand that this new taxonomy, although qualitative in initiation, can be quantified directly, though not without effort. "...[W]ith sufficient rigor in the definitions, a qualitative system could be made quantitative by having judges rate or scale each descriptor in terms of its involvement in a particular task."[24] The choice of the Human Ability Requirements approach is driven in large part by this fact; the quantitative classification of this method is proven more advanced than that of other dominant approaches.[24]

This thesis does not attempt to quantify fully the new definitions nor the taxonomy presented. Instead, it seeks to present an understanding of classification, taxonomies, the two-hand problem, a possible taxonomy, and the requirements to obtain a quantified taxonomy.

2. Evaluating Classificatory Systems

Once the following issues have been addressed fully, the question of how to judge the resulting taxonomy can be presented. Fleishman and Quaintance's Taxonomies of Human Performance points out that at the time of its publication, "the methods for evaluation classificatory systems have been particularly neglected."[24] The presentation of criteria is similar to many other experimental design approaches. There are basically three primary type of criteria for use in evaluation; internal validity, external validity, and usage. Internal validity requires that the system is internally consistent and complete. External validity requires that a system is capable of accomplishing what it was designed for or for predicting a behavioral or leaning effect. Usage is whether the system is actually used by the desired audience.

C. APPLICATION OF THE ABILITY REQUIREMENT APPROACH

1. Conceptual Background

One approach to taxonomic development, as detailed in the Taxonomies of Human Performance [24], lies in the use of known parameters of human performance as a basis for describing and classifying tasks. A major source of information is the literature on human abilities identification. This extensive research is based on the intercorrelations obtained among task performances in a variety of performance areas (e.g., cognitive, perceptual, psychomotor). Here individual differences are exploited to gain insights about common processes required to perform different groups of tasks. Abilities are defined by empirically determined relations among these observed separate performances. Typically, correlational studies have been carried out in the psychometric tradition and, until recently, little attempt has been made to integrate the ability concepts developed there into the more general body of psychological theory.

To review briefly, ability refers to a more general capacity of the individual such as Verbal Ability or Spatial Visualization, related to performance in a variety of human tasks. These abilities are relatively enduring attributes of the individual performing the task. The assumption is that specified tasks require certain abilities if performance is to be maximized. Tasks requiring common abilities would be placed within the same category. Factor-analytic studies or other clustering methods, based on the correlations among tasks (or test) performances, form the initial bases for identifying these ability dimensions.[24]

2. Derivation of Human Abilities

In order to understand the creation and application of human abilities in task classification it is important to outline the experience and method of their derivation. The process presented in the rest of this section are presented in two diagrams, Appendix A, Development of a Classification of Human Ability Requirements and Appendix B, Application of a Classification of Human Ability Requirements. In this area of research, the need to establish abilities is based first on the creation of ability categories based on experts' understanding of the area of human performance under study. This expert understanding leads to the qualification of hypothetical human ability categories based on the area under study. Once these hypothetical categories exist, the experts then create a set of tasks which are expected to denote and separate each of the abilities. These tasks are then administered to a standard sample of users and data is collected to obtain correlations between the tasks and abilities are obtained. These correlations are then subjected to analysis using factor-analytic study. These abilities can then be further refined utilizing the qualification of additional hypotheses, and more studies can be performed to sharpen the definitions of these abilities. "Factor analysis methods of clustering are used to return the fewest independent abilities that are most useful and meaningful in describing human performance across a wide variety of general tasks."[24]

Based on the review of previous work, it can be stated that much of the empirically based categorization of human abilities comes from the above correlational and factor-analytic studies. The categories are empirically representative of derived patterns of responses to task requirements.

All areas of human performance have not been thoroughly analyzed, although substantial work has been conducted in the identification and quantification of the major areas of basic human abilities. (Interestingly, it is this lack of comprehensive analysis which provides the subtext for the extension to hand-related abilities in this thesis.) The work of Fleishman and associates has gone a long way in establishing a refined set of abilities encompassing a large part of the cognitive, perceptual, psychomotor, and physical areas of human performance. The stating and definition of the major areas of human performance as ability categories has provided a coverage of a large range of human abilities required for the performance of most tasks; in the real world. All of the work completed in the area of human performance assumed real world physics. In some situations, this assumption holds as the real world is moved to the synthetic environment, while at other times the abilities need to be further refined, redefined, or extended in order to again cover the broad range of human abilities possible in the synthetic environment.

3. Development of Ability Dimensions and Measurement Systems in the Taxonomy Project

The basis for the real world abilities presented in this thesis is work completed in the Taxonomy Project. The objectives of this project were to first derive an initial classification system of unambiguously defined abilities which were best substantiated in previous human performance research and the creation and refinement of a rating scale methodology with which the ability requirements could be described as classifying tasks. The abilities are delivered in a format similar to that presented in Appendix E, Definitions and Abilities Rating Scales.

4. Development of Scaling Procedures for Ability Ratings in the Taxonomy Project

The work of the initial Taxonomy Project was very encouraging, but one of the major areas of refinement was the methodology for ratings abilities. Much of the refinement of the ability scales was centered around the careful specification of distinctions among abilities to reduce ambiguities in the definitions and the revision of the scaling technique. The main thrusts of the refinement of the abilities requirements definitions was the inclusion of more operational terms. The rating scale was moved from a three point system to a seven point system. The three point system was centered on the experts rating each of the tasks under study as "not involved," "baseline," or "critical" (rating 0, 1, and 2, respectively). The seven point scale was a behaviorally anchored rating technique that anchored both the high and low ends of the scale with definitions and task examples.

A seven point scale was used in the work contained in this document, but with further refinements. The actual scales developed for this thesis are presented in Appendix E, Definitions and Abilities Rating Scales. These scales and the extensions that were employed are described more fully in "Development of Scaling Procedures for Ability Ratings in the This Project" on page 29.

This work is based in large part of refining work that has already been validated in the world of task taxonomy research and has been detailed in F-JAS.[22, 24] Although this work is itself not new, it is the coordination of this information specifically for two-handed research along with its presentation to other communities that is of interest. The subset of the F-JAS taxonomy that is being utilized as a basis for the handed taxonomy is:

CONTROL PRECISION is the ability to move controls of a machine or vehicle; involves the degree to which these controls can be moved quickly and repeatedly to exact positions.

MULTILIMB COORDINATION is the ability to coordinate movements of two+ limbs (for example, two arms, two legs, or one leg and one arm), such as in moving controls. Two+ limbs are in motion while the individual is sitting, standing, or lying down.

ARM-HAND STEADINESS is the ability to keep the hand and arm steady. It includes steadiness while making an arm movement as well as while holding the arm and the hand in one position; does not involve strength or speed.

MANUAL DEXTERITY is the ability to make skillful coordinated movements of one hand, and hand together with its arm, or two hands to grasp, place move, or assemble objects like hand tools or blocks.

FINGER DEXTERITY is the ability to make skillful, coordinated movements of the fingers of one or both hands and grasp, place, or move small objects. This ability involves the degree to which these finger movements can be carried out quickly.

WRIST-FINGER SPEED is the ability to make fast, simple, repeated movements of the fingers, hands, and wrists. It involves little, if any, accuracy or eye-hand coordination.

SPEED OF LIMB MOVEMENT involves the speed with which a single movement of the arms or legs can be made. This ability does not include accuracy, careful control, or coordination of movement.

One of the problems with the ability requirements approach, and with other refined approaches, is that the abilities are initially defined in a subjective manner. Once the taxonomy is created, the abilities can be empirically refined by studying pattern consistencies in each of the different tasks. The empirical analysis presents a problem when the developers want to explain the numbers and their meaning. It is at this stage that the subjectiveness again comes into play as the analyst attempts to translate the empirical findings and definitions for each factor into a semantic definition via labelling. Through examination of the empirical data, the analyst must attempt to present the factors with a single label and definition that best describes the commonalities and differences discovered.

30. WRIST-FINGER SPEED — This ability is concerned with the speed with which discrete movements of the fingers, hands, and wrists can be made. The ability is not concerned with the speed of initiation of the movement. It is only concerned with the speed with which the movement is carried out. This ability does not consider the question of the accuracy of the movement, nor does it depend upon precise eye-hand coordination.[24]

"There is nothing capricious about this or any other ability definition."[24] The work that went in to defining, empirically proving, and stating this, and all other ability definitions is represented by a rational, repeatable, and verifiable process. The issue, as with most other system development reliant on expert judgement at any stage, is that the extensive amount and comparison of information that went into this definition tends to be "private" to the expert and may not be knowable in words by the expert or the other parties involved.[24]

D. DEVELOPMENT OF A TAXONOMY FOR TWO-HANDED INPUT IN A VIRTUAL ENVIRONMENT

1. Touch Issues

The addition of five touch-related abilities is required for the application of the taxonomy in a virtual environment. The reason for this is based in large part on the real world and in the assumptions that were made about the development of the initial Human Abilities Definitions.

The real world is made up of solid objects. This extends itself to the extent that humans can feel most things that they attempt to touch (stagnant air being an example of where this does not hold.) This is not a special rule, it is the norm for humans functioning in the real world. In a synthetic world, this rule does not hold. Objects in an VE are not physical in nature, although the use of specialized devices can sometimes provide the sensation of touch to a user when interacting with such a virtual object.

> GROSS TOUCH is the ability to obtain the simple message that an object is being touched; no information is transmitted concerning movement, texture, or detail.
>
> FINE TOUCH is the ability to obtain complex object information through touch; no information is transmitted concerning movement.
>
> FORCE REFLECTION is the ability to feel an external, dynamic force; no information is transmitted concerning texture or detail.
>
> TEMPERATURE DISCRIMINATION is the ability to feel a temperature gradient in an object, a difference between an object's temperature and the room temperature, or extreme temperatures.
>
> PAIN DISCRIMINATION[1]

This results in a new Two-Handed Abilities Definition list:

> GROSS TOUCH is the ability to obtain the simple message that an object is being touched; no information is transmitted concerning movement, texture, or detail.
>
> FINE TOUCH is the ability to obtain complex object information through touch; no information is transmitted concerning movement.
>
> FORCE REFLECTION is the ability to feel an external, dynamic force; no information is transmitted concerning texture or detail.

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1. The initial list of new abilities did not include any mention of humans' ability to feel pain. The addition of Pain Discrimination is based on discussions that have occured over the course of 12 months with various specialists in this area. The ability is being included in this version of the thesis, although no scales nor definitions are being presented as there are ethical and procedural questions related to these artifacts that have not been resolved.

TEMPERATURE DISCRIMINATION is the ability to feel a temperature gradient in an object, a difference between an object's temperature and the room temperature, or extreme temperatures.

PAIN DISCRIMINATION

CONTROL PRECISION is the ability to move controls of a machine or vehicle; involves the degree to which these controls can be moved quickly and repeatedly to exact positions.

MULTILIMB COORDINATION is the ability to coordinate movements of two+ limbs (for example, two arms, two legs, or one leg and one arm), such as in moving controls. Two+ limbs are in motion while the individual is sitting, standing, or lying down.

ARM-HAND STEADINESS is the ability to keep the hand and arm steady. It includes steadiness while making an arm movement as well as while holding the arm and the hand in one position; does not involve strength or speed.

MANUAL DEXTERITY is the ability to make skillful coordinated movements of one hand, and hand together with its arm, or two hands to grasp, place move, or assemble objects like hand tools or blocks.

FINGER DEXTERITY is the ability to make skillful, coordinated movements of the fingers of one or both hands and grasp, place, or move small objects. This ability involves the degree to which these finger movements can be carried out quickly.

WRIST-FINGER SPEED is the ability to make fast, simple, repeated movements of the fingers, hands, and wrists. It involves little, if any, accuracy or eye-hand coordination.

SPEED OF LIMB MOVEMENT involves the speed with which a single movement of the arms or legs can be made. This ability does not include accuracy, careful control, or coordination of movement.

2. Development of Scaling Procedures for Ability Ratings in the This Project

The scales for the pre-existing F-JAS abilities definitions utilized for this work can be found in Fleishman Job Analysis Survey - Rating Scale Booklet.[22] The scales for the four human abilities developed in this study can be found in Appendix E, Definitions and Abilities Rating Scales; Pain Discrimination does not have a scale at this time. A complete understanding of the abilities in this Appendix is presented in the following section.

The anchored definitions were defined through an analysis of the complete presence and absence of the ability under review. While the definition is meant to describe the ability in a general approach, the anchors are specific in their presentation of the ability. The examples, presented on the right side of the scales, are an even more refined presentation of the ability drawing on real world tasks. The tasks chosen are from different areas of human interaction, but all are examples related to touch via the hands. This is one limitation to the generalization of the scales at this time to other areas of research. This limitation is inherent in the process used to develop HARs. As this process is iterative it will develop characteristics based on the problems it is applied to; at this time only the THWH interaction problem. When these new human abilities are applied to other topic areas the examples will most likely evolve to become less hand-centric.

3. Presentation of New Human Abilities

The rating scales and definitions for the four new abilities defined in THWH interaction are presented in Appendix E, Definitions and Abilities Rating Scales. As stated before, the format that the abilities are presented adhere to the format defined by Fleishman and used in F-JAS. Each of the human abilities is presented with a simple definition at the top. While this definition can be used by any person involved in a project, it is hoped that the researcher has some experience with the use of rating systems. The importance of this point in the use of the definition centers on the requirement that the definition not be interpreted broadly. This problem is partially alleviated by the inclusion of the ability comparisons.

The human ability comparisons show how the ability being covered compares with similar abilities. This comparison presents a further understanding of what the exact skill is that is under review. This comparison is helpful to researchers and laymen in narrowing the understanding of the definition. The ability is then refined through the use of two types of examples.

The left side of the scale presents complete absence and complete presence definitions in a format similar to the broad definition. This presentation gives the researcher more specific definitions. When coupled with the real world examples, presented on the right side of the scale, the researcher can build a strong mental model of the area covered by the ability.

One note of major importance is that the scale values are meant to show importance to a problem, not amount. When reviewing a task, one skill may be utilized ninety percent of the time, but be of low importance while another skill is used only ten percent but is of prime importance. The scaled value for the first ability would be low while the second value would be high. A common example is that of eye tracking. When studying attachment speed in an eye tracking problem the majority of time is spent with the eye moving in a general pattern. When the object of interest is presented the eye attempts to center itself on this object in the shortest time possible, with the highest accuracy. The general movement of the eye, while occurring for the majority of the experiment, is of low importance when considering the speed of attachment to the object. This is sometime non-intuitive to lay practitioners and is one of the largest sources of error in usage of the scales by non-researchers.[24]

IV. CLASSIFICATION AND TAXONOMY APPLICATION

A. APPLICATION TO VE RESEARCH

The taxonomic method presented in Chapter III can be used to classify any aspect of human abilities. The F-JAS system[22], available from the Management Research Institute, covers a broad range of human abilities which can be used as a basis for work in the virtual environment. In our work with this system, one main limitation for usage in VEs has been discovered inherent in the assumptions made by the original researchers. The initial research and resulting classifications assume the real world. As examples, a human in the real world can feel things that he picks up with his hand. He can assume that the ground will not move out from under his feet, except in rare circumstances (shipboard or California.) Understanding the repercussions that this assumption has on research in VEs, and further understanding how to remove this assumption, has preoccupied a great deal of the initial work in this project.

This section presents a overview of the development of specific classifications for VEs, the analysis inherent in this problem, the methods used, and the resulting knowledge and tools. This work focuses on a number of aspects of the two-handed, whole-hand interaction (THWH) problem explained previously. Additional examples and explanations are mentioned in reference to another classification developed in a similar fashion at the Naval Postgraduate School by the author. This second area of research centers around a classificatory system developed and utilized to study active human locomotion in virtual environments[16]. Both classificatory systems are based on F-JAS human abilities and have been extended to remove assumptions that are invalid in virtual environments. While both classifications are complete and are usable by practitioners and researchers, the THWH classification is more refined in terms of the depth of the problem being analyzed and the time spent on the HARs.

1. Definition of the Problem

The problem presented in brief in this paper is that of two-handed, whole-hand interaction. Specifically, this section presents the conceptual analysis of the general task of handed interaction, the development of a taxonomy and classification for handed interaction, the application of absence/presence and scaled analysis using the classification, and the conclusions that can be drawn. The approach is presented in two process diagrams, Appendix A, Development of a Classification of Human Ability Requirements and Appendix B, Application of a Classification of Human Ability Requirements.

The first process presents the development of classifications of human abilities that do not exist or for the understanding and extending classifications that already exist. Work in this process seeks to develop a qualified classification as well as use it to solve a VE problem. The second process assumes that there is a qualified classification already completed for the human abilities being studied.

In the real world, each of us possesses certain abilities that we use to perform tasks. Each of us knows how to pick up a glass, or type of a keyboard. However, when we enter the virtual world, constraints inherent to the technology do not allow us to use the same abilities we developed for the real world in an exact and identical fashion. While each of us can precisely place the cup into a dishwasher in the real world, we could not do so in a virtual world due to multiple limitations of the technology. This limitation can only be overcome with the use of specialized devices. The real world scenario shows three tasks and the human abilities required to perform each. However, when devices are used in the virtual world to perform these tasks, the mapping is quite different. This is typical of VE interfaces.

2. Analysis of the Real World

With a strong understanding of the problem in place, the first step is to develop the human abilities that are involved in solving the problem. The method most easily understood is the delineation and analysis of human tasks related to the problem. In terms of THWH we defined as many variations of humans using their hands to solve a problem, in a number of situations and with a number of objects. This list was developed with no limitation on its length, but was instead meant to be inclusive of THWH. A shortened list of these tasks is covered in Appendices F, A/P for Real World Tasks Using F-JAS, G, A/P For Real World Tasks Using THWH, and H, Scaled Real World Tasks Using THWH

This list was then used to analyze the present human abilities defined in F-JAS. An absence/presence review of each task was performed, with the intention of looking for aspects of the task that were not being covered by the present HARs. Special attention was paid to aspects of the tasks which were known to change when the tasks were performed in VEs. Although this knowledge would not be accessible to a novice first approaching the problem, previous experience prevented us from ignoring this knowledge. Additionally, although anyone can develop or extend HARs, the more complete classifications will be developed by topic experts who possess this type of knowledge.

Aspects of the tasks that were not covered by the present HARs were written down and collected in order to look for similarities and differences in these "new" human abilities. Again, relying on topic expert analysis and common sense, the "new" human abilities were grouped and a small set of new HARs were defined as extensions to the present classification. In the THWH work, the HARs developed were completely new, and were not based on any previously exiting abilities in F-JAS. In this problem, five HARs were added to cover abilities that were previously undefined in the classification. This is in contrast to the HARs that were added to the problem of locomotion, which were extensions of two previously existing abilities.[15,16]

The classification now needed to be completed by developing definitions of the new HARs, development of the seven-point, behaviorally-anchored scales that each would need, and a further review of the complete classification for completeness. The definitions were built based on the wording, terminology, and approach of the definitions for the pre-existing HARs. Special attention was paid to delimiting the exact nature of the ability that is covered by each HAR. This information is also used to build quick charts on how the HAR under review is different from similar

HARS; this can be seen at the top of the scale in Appendix E, Definitions and Abilities Rating Scales.

With the classification definitions completed, the task became that of creating or referencing the scales that are needed for each of the abilities. As mentioned before, each of the definitions utilizes a seven-point, behaviorally-anchored scale in addition to the definition and comparisons. The creation or utilization of each of the scales is a more iterative task than the creation of each particular definition - these scales are expected to change over time as more tasks are analyzed. An example of such a scale can be seen in Appendix E, Definitions and Abilities Rating Scales which presents a scales for four of the five new HARs. The reader will note that the scale presents two more pieces of data for use in analysis; extended definitions and task examples. The extremes of the scale, 1 and 7, are anchored with extended definitions. The complete presence of the ability, at 7, and the complete absence of the ability, at 1, are presented in the definitions. These definitions are on the left side of the scale. Along the right side of the scale are task examples, anchored at points equivalent to their presence, to give the analyst real world grounding.

At this point, the classification is usable in the analysis of tasks in the real world or the virtual environment. As a note, the development of taxonomies is an iterative process and is subject to revision as new systems are developed. This first revision of the taxonomy and classification does not purport to be complete nor immutable for all systems that may exist.

One of the first applications of the classification is in the re-analysis of the real world tasks using an absence/presence analysis. The application of the absence/presence analysis to the series of THWH tasks in the real world can be seen in Appendix F, A/P for Real World Tasks Using F-JAS. This chart presents the analysis of a small subset of THWH tasks, primarily so that the reader can see the level of the tasks. The absence/presence analysis of the tasks is useful for reviewing the complexity of the tasks from a multi-modal viewpoint. One thing that we discovered in these types of analysis is that the most innocuous seeming real world tasks are sometimes the most complex problems from a HAR standpoint.

The next step in the application of the classification is the analysis of the tasks using the scaled analysis. The application of the scaled analysis to the series of THWH tasks in the real world can be seen in Appendix H, Scaled Real World Tasks Using THWH. The tasks being analyzed, as well as the classification, are the same as in the absence/presence analysis. The use of the scaled analysis is crucial when the researcher seeks to understand the weight of each HAR in the task being solved. Whereas the a/p analysis allows for quick and simple comparison of tasks based on the abilities that they require, the scaled analysis allows for a comparison of tasks that utilize the same abilities.

3. Analysis of Real World Tasks (internal validity)

One of the requirements for a comprehensive classification is that it cover a broad range of real world tasks that are supposed to rely on the human abilities under study. One note on this concept, the area of study must be comparable to the area that the classification purports to cover. Attempting to apply a classification to a new area of tasks may uncover presumed errors in the tasks, based on the understanding of the taxonomy, or in the taxonomy, based on the understanding of the tasks. This misapplication of a classification is not uncommon, particularly in common literature; daily papers, weekly news magazines, television news.

Another point related to the application of a classification, is that there are times when the taxonomy may seem to fail at the describing or including an environment if the area or tasks under study are new. This can be based on the fact that the areas or research or tasks involved, which are explained completely by the taxonomy, changes. The work that was done in the Taxonomy Project, which developed the MARS and later F-JAS, was based on an understanding of how humans interface to the extent that was then possible: the real world. The taxonomy requires revision, which is being studied in part in this thesis, based on the addition of virtual world tasks to the possibilities of human interaction. Until now, the ability to feel was not an assumption but a fact. With the development of advanced computer systems this has changed the underlying problem in a way that, although foreseeable, was not concrete at the time of the last major revision. As stated before, taxonomies can always be placed in a situation where revision may be necessary based on new areas of coverage. This situation does not invalidate the taxonomy but simply requires a review for possible revision or extension.

With this understanding, the analysis of the real world through the study of real world tasks is the first analysis that as performed. The original taxonomy, and therefore the abilities taken from it, were based on real world tasks. With the addition of the three new tasks, required for the virtual environment, I decided to see how well the new taxonomy covered the real world.

4. Analysis of the Virtual World

With the real world analysis documented, the researcher can now approach the same tasks implemented in a virtual environment. This analysis can be performed to build a realistic virtual environment, in which case the verisimilitude is meant to be exact, or to build an abstract environment with utilizes the human's inherent skills in an optimal manner. In either case, the approach is similar to that of the real world.

The first step is to again perform an absence/presence analysis of the tasks while in a virtual environment. An obvious question here is "which virtual environment?" When discussing the real world, assumptions can be made about the common experiences among all humans. When discussing a virtual environment, what are the metrics? This is the point where the problem could devolve into a hardware and software analysis. The answer that we offer to this query is, "it doesn't matter what equipment is being used, a human is still a human." The basis of using HARs is that the tasks are analyzed based on the human's abilities. The abilities of a human does not change when the human moves from one environment to the other. When a human walks around on the ground, on a train, or on a boat, the abilities utilized by the human are different but the human's abilities haven't changed. So the analysis of a virtual environment is predicated on the use of equipment that the VE is being built upon.

The tasks that were then analyzed using the new taxonomy in the real world; this analysis was done independent of any thoughts of placing the subject in a simulated environment. This analysis is presented in Appendix G, A/P For Real World Tasks Using THWH. The tasks were then analyzed using the newly developed scales. This analysus is presented in Appendix H, Scaled Real World Tasks Using THWH.

5. Development of Tests

Three tests were developed in order to validate the Fine Touch aspect of THWH interaction. Each of these tests is based on those previously developed for tasks defined by Fleishman. Each of these tests is meant to separate and discern each of the tasks under study.

Braille Pattern Analysis

> This test is a multiple-item performance test that requires subjects to feel a set of braille letters and duplicate the pattern on paper with pen. The testing unit consists of a series of braille letters arranged in discrete sets by word. The subject is given a pen and paper in order to reproduce the braille pattern. The test measures time and accuracy of touch.

Raised/Depressed Fine Pattern Analysis

> This test is a multiple-item performance test that requires subjects to feel a set of raised or depressed letters or patterns and duplicate the patterns on paper with pen. The testing unit consists of a series of letters and patterns arranged in discrete sets. The subject is given a pen and paper in order to reproduce the letters and patterns. The test measures time and accuracy of touch.

Button and Hole Test

> The testing unit consists of a button and whole cloth kit, similar to a button-down shirt, hidden from the subject's view behind a curtain. The subject is required to button a set of six buttons using both hands. The test measures time and accuracy of touch.

6. Application of Tests

> Two basic psychophysical questions in evaluation are: (1) With a given set-up, how good is the task performance or realism of the subjective experience? (2) How does a change in the set-up improve the performance of a given task, realism of the experience, or both? [18]

One of the approaches to the quantification of the taxonomy is to develop define real world tests that can be used to prove the validity of the three new human abilities requirements that were presented, the haptic abilities. In presenting these abilities for study, a solid understanding of the studies that were performed to develop the original taxonomy is required. Although re-running the original test are not required for this work, these studies provide a basis for the quantification of the experiments to be run.

The work presented in this thesis presents a number of paths to complement and extend the research. A number of the paths extend the work of this taxonomy through quantification and refinement of the taxonomy itself. At present, the taxonomy presented in this thesis is based on expert analysis and has not been extensively quantified; this is not uncommon in taxonomy research and development and is actually valid in providing a taxonomy for general usage.[24] With this understanding, the following examples are presented for possible future study.

7. Real World versus Virtual World Experiment

The approach that is being taken seeks to compare the application of abilities to tasks in a real world and abilities to tasks in a virtual environment. The tasks which were used to previously define the human abilities requirements were used as a starting point to define the experiments to be run in the RW and in the VE.

The approach that was taken was to first complete the development of the extended human ability requirements (HARs) beyond what was completed in the real world. This was previously explained, but revolves predominantly about the addition of haptic based abilities that were assumed in the real world but that are separate abilities in the virtual environment.

All of the experiments that were used by other researchers in order to quantify the original HARs are then collected and primed for user interaction. At this time the extended HARs are used to develop experiments in the real world that allow the observers to quantify each of the haptic areas.

At this point, all of the experiments that exist in the real world are implemented in a virtual environment. It is at this time that some of the initial limitations of the VE begin to manifest themselves, but it is imperative that these limitations be recognized, analyzed, and their effects limited in order to remove confounding factors. As many of the limitations of the VE that are discovered at this point are not solvable with present technology, these limitations are documented for discussion in the conclusions.

The users are then run through all of the experiments in the RW and in the VE with the experimented capturing various types of data; capturing the pertinent experimental data along with expert observation, video recordings, and user comments.

- Define Human Abilities Requirements (HARs) for two-handed interaction in a virtual environment.
- Coordinate the implementation of the original experiments used to define the HARS.
- Develop experiments in the real world that define the added HARs developed for the VE.
- Duplicate all of the experiments from the real world in a virtual environment to the best of the experimenters abilities.
- Proceed to have users perform all experiments in the RW and in the VE, capturing the pertinent experimental data (experiment specific) along with observation data, video recordings, and user comments.
- Choose a set of the taxonomy tasks (criteria to be defined later) and implement their real world tests in the VE.

a. *Real World and Virtual World Tests*

The tests for the THWH taxonomy were not developed in the VE because of the development of a series of similar experiments related to a taxonomy of Active Locomotion developed at NPS at the same time. This set of experiments follows the analysis above, culminating in the analysis of a series of real world and virtual environment experiments. This work is deatiled in [15] and [16].

8. Additional Comparisons

The information that is derived above shows how the classification can be used internally to a study to allow for choices of training methods or equipment. In addition, the information developed for tasks or devices in the real world or the virtual environment in one study can be used for external comparisons. This data can be used to compare devices or tasks across research organizations, generations of devices, or research methods. Multiple comparisons are shown in Appendix C, Comparisons Using Classifications. Two of the more prominent comparisons are presented below.

a. *Application of Taxonomy to Devices*

The assumption of equipment in the analysis of virtual environments is one of the areas that the development and application of classifications addresses. A major problem facing practitioners and researchers today is what equipment should be used to implement virtual environments in order to solve a chosen problem. In the future, as more people begin to adopt virtual environment technology to develop possible solutions, the topic expert knowledge presently used by researchers will not be as forthcoming. These newcomers will understand the problems that they seek to solve, but they will not know how to build their solutions in a VE. These researchers will be able to refer to previous research or existing devices that have been analyzed using the a/p or scaled analyses.

b. *Application of Taxonomy to Existing Studies*

One of the keys to the validation of a general taxonomy is to ensure that it rationally encompasses the whole of the existing literature addressing the taxonomy's study. This should be done before it can be rationally stated that the taxonomy developed in general in nature and not another example of a constrained problem.

B. ANALYSIS OF MEDIC MANUAL

In support of the DARPA project ongoing at NPS the Army 91B Medic Manual was placed under review using the THWH classification. This is detailed in Appendices K, Analysis of Soldier's Manual — CMF 91 General Medical Tasks and L, A/P for Medic Analysis using THWH.

V. CONCLUSIONS

A. OVERVIEW

The goal of this thesis was to present a standard approach and method to classifying human abilities and scrutinize this method through its application to real world problems. In order to accomplish this a proven method of human ability classification was adopted and extended for use in a new type of problem (non-real world.) The methodology was then applied to a problem of interest to the Virtual Environment community; handed interaction, and later to the problem of active locomotion, detailed in [15] and [16].

This thesis demonstrates that developing and applying common languages to methods of human interaction can help to define the way humans operate. The use of classification also proved to be the first tool developed for human VE research that can be applied across studies.

This thesis is only the first step in the further development and adoption of this method of classification research to human VE research. While this thesis displays the advantage of using classifications for observation, analysis, and design of human interaction methods, understanding of the methods application in VEs is far from complete. In addition, the application of this method to THWH interaction represents only a small subset of the areas of human skills that exist and should be studied.

The hope is that this thesis will open up the world of VE research to a new approach to human study. This chapter presents final comments on the use of classifications in VE research, the THWH interaction problem, the 91B Medic problem, and areas of future research.

B. THE VALUE OF CLASSIFICATIONS

The use of Human Ability Requirements for human performance evaluation has already proven its value in other research communities.[24] While this thesis is not the first one to develop or apply a classification (taxonomy) to VE research, it is the first one to use a previously validated methodology. The application of this methodology has presented a logical and direct way for what has, up until now, been a widely disparate set of research interests.In a field such as VE research, where humans play a integral role, it is important that methods based on human tasks be developed and applied in standard ways.

Many of the issues raised in this study were discussed in earlier studies. Researchers from a variety of backgrounds have attempted to build classifications for aspects of human interaction; these attempts have often mistakenly been called taxonomies. The methodology presented here is the first attempt at providing a general approach to this problem, independent of study, device, or research specialties. While this thesis attempts to provide such a tool, it is by no means complete nor infallible.

C. THE VALUE OF A TAXONOMY FOR THWH INTERACTION

The use of Human Ability Requirements for understanding two-handed, whole-hand interaction provides the first general approach to understanding this heavily studied area of human interaction. Sturman's work provides a strong understanding, and general framework, for whole-hand interaction and is complemented by this approach to two-handed aspects. Unlike Sturman's methodology, this one to based on a previously validated methodology. This classification and methodology presents a logical approach for this field of research.

D. THE DARPA 91B MEDIC INITIATIVE

Initial research initiative into immersion the 91B Field Medic into a virtual environment had concluded. A demonstration was provided at Sandia National Labs without major participation from either the University of Pennsylvania or the Naval Postgraduate School. The demonstration presented the final system being delivered to DARPA. The system was based on a simply point-and-click interface along with pre-ordained medical actions that would normally be performed by military personnel. Although the training system did not address the actual skills trained by the military using the manual presented in Appendix L, "Analysis of Soldier's Manual — CMF 91 General Medical Tasks", there were some equivalent tasks.

As an example, the SNL system would display a comical human avatar on a computer monitor and display information about the patients state. The user must decide what the medical situation is and perform the correct actions to alleviate the problem. Assuming that the patient has a breathing problem, one of the fist tasks to be performed would correlate to the skill 081-831-0018 - Open the Airway. In the SNL simulation, the user would direct the comical avatar to perform the required actions using the point-and-click interface. If the user selected to correct actions, the avatar would display a pre-recorded set of actions showing how to perform the required actions on the injured avatar. This scenario is possible for a variety of medical conditions covered in Medic training.

The above solution, though interesting, does not train any of the skills that the military is seeking to train using their present methods. While some of the cognitive skills involved with the patient analysis may be transferred using the SNL system, none of the skills required to actually analyze the patient's physical states transfers. The best hope for the SNL system is that the Medic being trained is able to memorized the steps involved in the procedures. This system didn't solve the underlying problem due to both incompetence and inability on the part of the team members.

One of the major problems with this program is that there were no metrics defined at the beginning or the project as to what skills should be trained, how they should be trained, and how the training transfer should be measured. The methodology and taxonomy presented in this thesis provide tools that allow future researchers to address these issues. Using the THWH classification presented along with the 91B Field Medic training manual and personal interviews with field Medics, an analysis of tasks was possible. This is the data that was discussed earlier and is presented in Appendix K, Analysis of Soldier's Manual — CMF 91 General Medical Tasks or Appendix L, A/P for Medic

Analysis using THWH.

In reviewing the absence/presence analysis completed in these two appendices, the researchers or practitioners can quickly see which human abilities are required in order to train a user in a virtual environment in a method similar to training the same skill in the real world.

E. OPPORTUNITIES FOR FUTURE RESEARCH

The most obvious questions raised in this thesis is the applicability of this methodology to other areas of human VE research. While the method has been used within the field of human performance evaluation for a number of years, the ability to generalize this approach within human interaction studies is still undecided. The methodology described in this research should be studied in application to other areas of human research.

Verification and refinement of the classification developed herein, THWH, is another problem that demands more study. While the classification has proven useful in understanding the real world and technological studies also presented in this paper, it requires external validation by other researchers.

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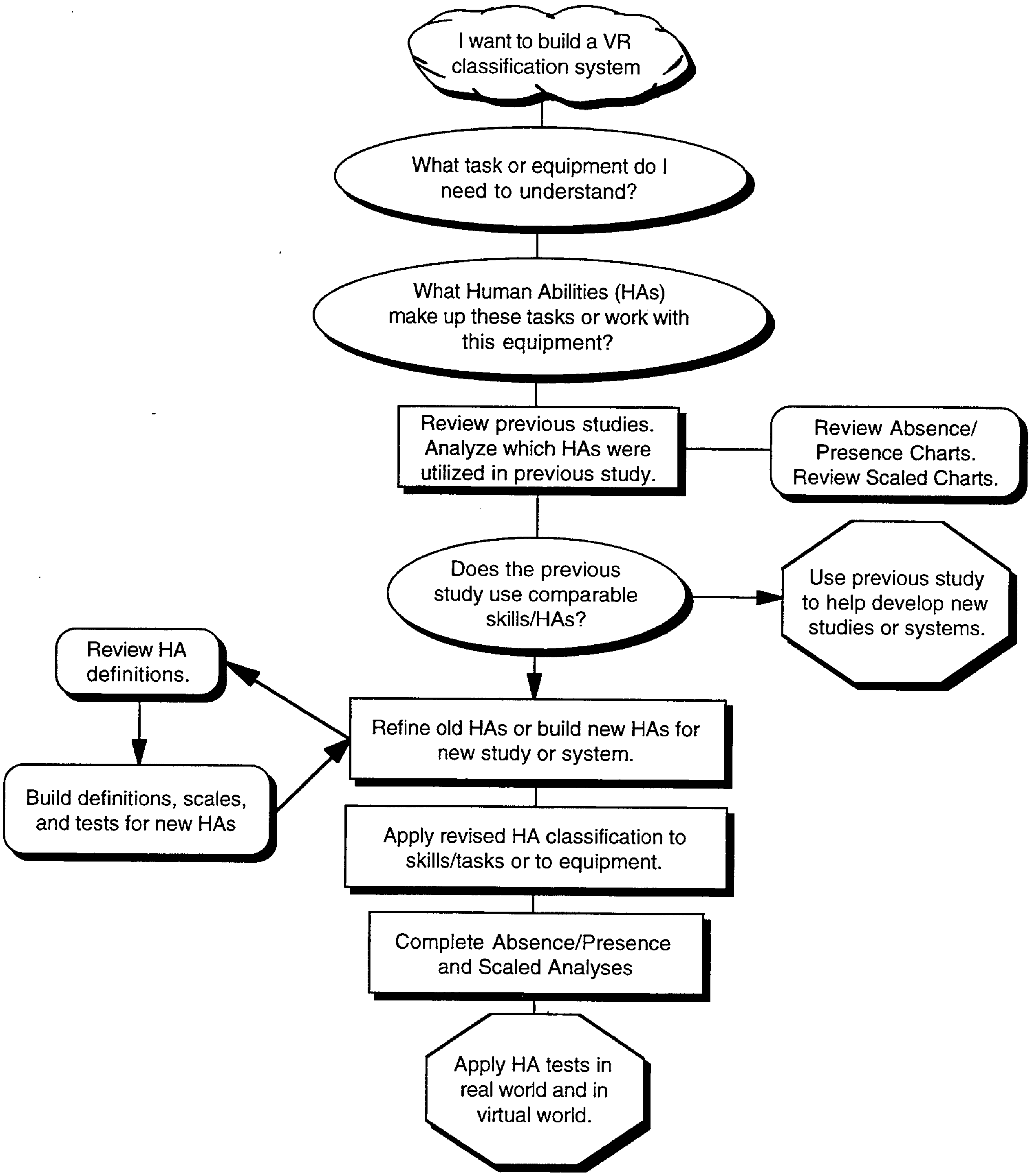
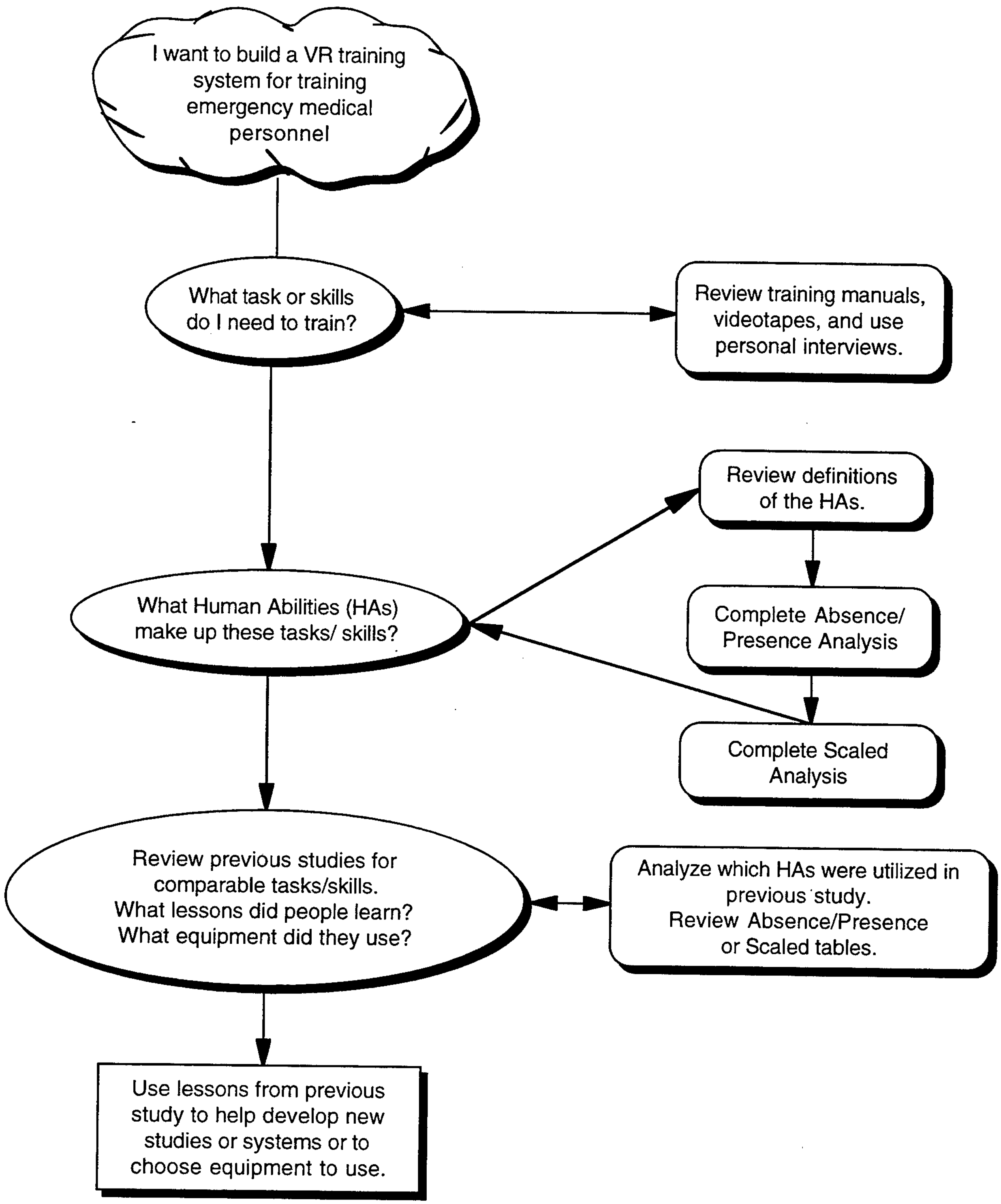
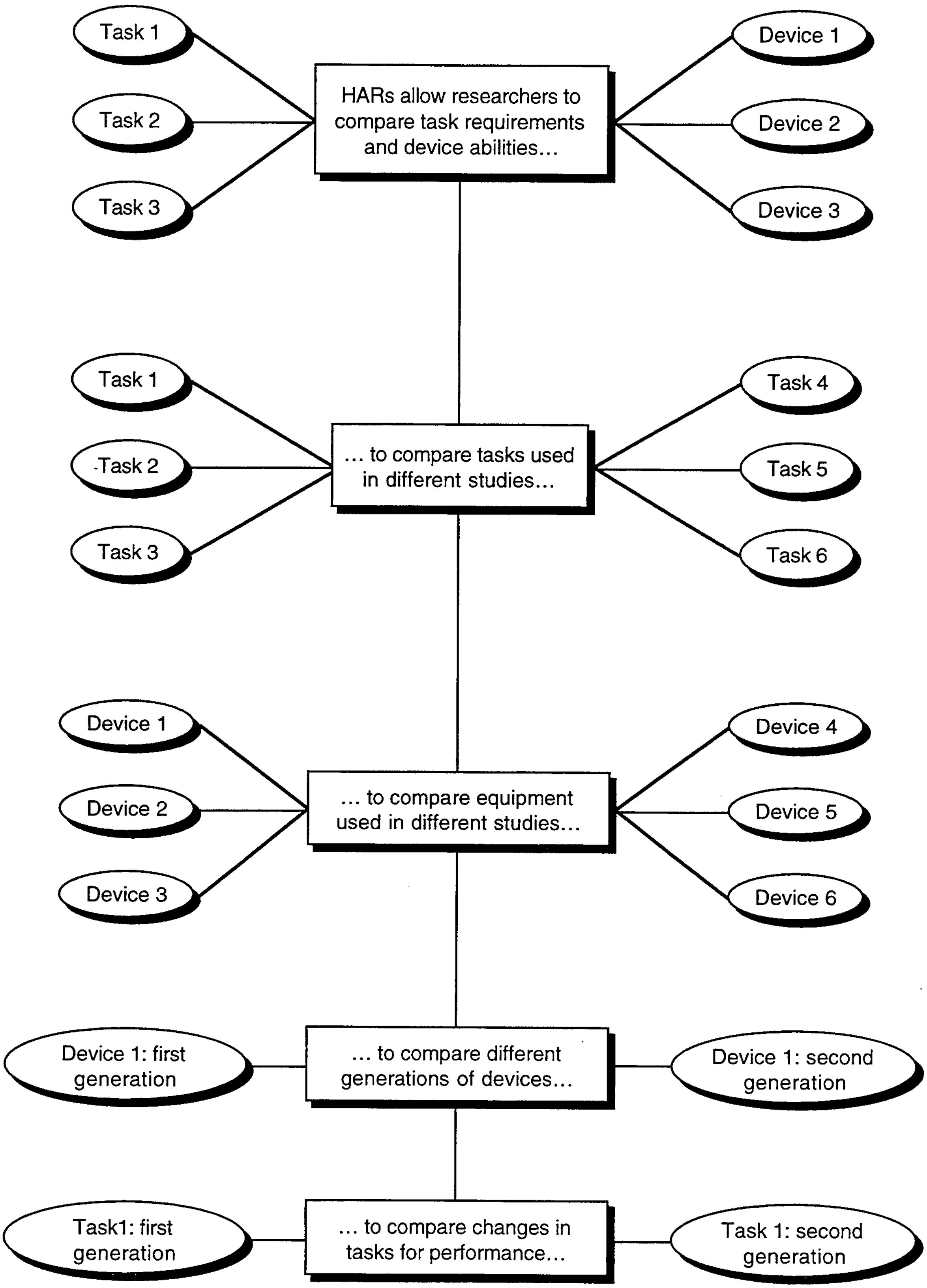
APPENDIX A. DEVELOPMENT OF A CLASSIFICATION OF HUMAN ABILITY REQUIREMENTS



APPENDIX B. APPLICATION OF A CLASSIFICATION OF HUMAN ABILITY REQUIREMENTS



APPENDIX C. COMPARISONS USING CLASSIFICATIONS



APPENDIX D. BENEFITS OF TAXONOMY RESEARCH

Scientific-Theoretical Benefits

Conducting literature reviews — Researcher and practitioners are faced with uncertainty when beginning literature searches in trying to apply terminology across experiments, in trying to apply lessons learned to new applications, and in trying to compare similar sounding research at different sites.

Establishing better bases for conducting and reporting research studies to facilitate their comparison — Standardized classification systems allow various studies to be compared. This is exceedingly important as research accumulates.

Standardizing laboratory methods for studying human performance — Along with the ability compare various studies, the creation of standard methods or terminology allows for comparison of research between laboratories.

Generalizing research to new tasks — One of the major problems facing human-computer research today is the need for new research to focus more heavily upon building on previous work. This problem can be resolved in part by allowing researchers to ascertain whether new areas of work are related at the task level to previous work.

Exposing gaps in knowledge — A comprehensive taxonomy allows researchers to review previous work and ascertain the areas outlined in the taxonomy that have been overly addressed or ignored.

Assisting in theory development — The development of any comprehensive theory to human performance is aided by the ability to classify performances.

Applied-Practical Benefits

Job definition and job analysis — The use of a taxonomy in job analysis allows for the classification of tasks required for presently existing positions, for new positions being developed, or for similarities between jobs. This feature, which was mentioned as a major benefit when Fleishman was doing much of his original work, has become an invaluable tool as continuous learning and reorganization become entrenched in today's modern business world.

Human-machine system design — In designing systems that interact with humans, from car dashboards to coffee machines to computers, the need to simplify the human's interaction can be facilitated only through an understanding of human strengths and weaknesses. The classification of human performance is a basis for the understanding of how humans operate in different areas of interaction.

Personnel selection, placement, and human resource planning — The choice and assignment of personnel to jobs can be facilitated by a practical extension to taxonomies which links the performance in abilities to areas of job requirements.

Training — The underlying problem of optimal training revolves around the need to understand the skills or attributes which are to be taught, the way in which humans learn or develop the aforementioned skills, and the methods that are best suited to a large positive training transfer. The classification of human tasks in each of these areas provides a first step to a broad understanding of this problem.

Performance measurement and enhancement — The creation and application of human performance standards can aid in the understanding of the effects of experimental changes in design as well as the measurement of training outcomes.

Development of retrieval systems and databases — The collection and classification of the broad area of human research could be facilitated and optimized through the use of a standard set of terms. This is becoming especially important as the proliferation of non-library based information sources has exploded through the use of the internet and will continue to expand with the promise of future information systems. [24]

APPENDIX E. DEFINITIONS AND ABILITIES RATING SCALES

NOT VALIDATED

Fine Touch

This is the ability to obtain complex object information through touch; no information is transmitted concerning movement.

How Fine Touch is Different from Other Abilities:

THIS ABILITY		OTHER ABILITIES
Can *feel complex information* such as texture, depression, or raises in an object using touch.	vs.	Can *feel simple information* telling only that something is present.
	vs.	Can *feel movement* over the skin.

Requires the ability to feel complex surface information such as texture, indentations, edges, or curved surfaces that adds information to the user in the task being studied.	7	
		— Read braille.
	6	
		— Center hands on a keyboard in order to touch-type.
	5	
	4	
	3	— Wind analog watch.
	2	
		— Use TV remote control buttons.
Requires the ability to feel simple surface information that adds information to the user for use in the task being studied.	1	

NOT VALIDATED

Gross Touch

This is the ability to obtain the simple message that an object is being touched; no information is transmitted concerning movement, texture, or detail.

How Gross Touch is Different from Other Abilities:

THIS ABILITY		OTHER ABILITIES
Can *feel simple information* telling only that something is present.	vs.	Can *feel complex information* such as texture, depression, or raises in an object using touch.
	vs.	Can *feel movement* over the skin.

Requires the ability to feel simple surface information to inform that there is a physical object present which is required for optimal completion of the task being performed.	7	
		— Touch-type on a keyboard.
	6	
		— Place bricks on a wall.
	5	
	4	
	3	
		— Lift pan from a burner.
	2	
		— Brush crumbs off a table.
Requires the ability to feel simple surface information which is not used for optimization of the task being performed.	1	

NOT VALIDATED

Force Reflection

This is the ability to feel an external, dynamic force; no information is transmitted concerning texture or detail.

How Force Reflection is Different from Other Abilities:

THIS ABILITY		OTHER ABILITIES
Can *feel movement* over the skin.	vs.	Can *feel simple information* telling only that something is present.
	vs.	Can *feel complex information* such as texture, depression, or raises in an object using touch.

Requires the ability to feel external moving forces against the skin required for optimal completion of the task being performed.	7	
		— Loosen a tight screw without letting the screwdriver slip.
	6	
	5	— Turning a non-power steering wheel in a sharp turn.
	4	
	3	— Pump up a tie using a hand pump.
	2	
		— Touch type on a membrane keyboard.
Requires the ability to feel external moving forces against the skin that adds no information to the task being performed.	1	

NOT VALIDATED

Temperature Discrimination

This is the ability to feel a temperature gradient in an object, a difference between an object's temperature and the room temperature, or extreme temperatures.

How Temperature Discrimination is Different from Other Abilities:

THIS ABILITY		OTHER ABILITIES
Can *feel temperature differences* in objects.	vs.	Can *feel simple information* telling only that something is present.
	vs.	Can *feel movement* over the skin.
	vs.	Can *feel complex information* such as texture, depression, or raises in an object using touch.

	Scale	
Requires the ability to feel temperature difference information, either hotter or colder, which is required for optimal completion of the task being performed.	7	
		— Touching a door to check for a fire situation on the other side.
	6	
		— Touching a glass to judge the state of the liquid inside.
	5	
	4	
	3	— Shaking another person's hand.
	2	
		— Stepping out of a 25°C house into a -5°C snowstorm.
Requires the ability to feel temperature difference information, either hotter or colder, which adds no information to the task being performed.	1	

APPENDIX F. A/P FOR REAL WORLD TASKS USING F-JAS

	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement
Type on keyboard	●	●	●	○	○	○	○
Type on keypad	●	●	●	○	○	○	○
Open door with punch lock	●	●	○	○	●	●	○
Use mouse	●	○	●	○	●	○	●
Open push door using horizontal handle	●	○	●	○	○	●	○
Open pull door using vertical handle	●	○	●	○	○	●	○
Open door using key and doorknob	●	●	●	○	●	●	○
Open door using doorknob	●	○	●	○	●	○	○
Turn light switch off	●	○	○	○	●	○	○
Read hardcover book	●	●	○	○	●	●	●
Drink from glass	●	○	○	○	○	○	●
Drink from mug	●	○	○	○	○	○	●
Write with pen on paper	●	●	○	○	●	●	●
Cut cucumber	●	○	○	○	●	●	●
Butter bread	●	○	○	○	●	●	●
Screw lid on jar	●	○	●	○	●	●	○
Dial pushbutton phone	●	●	●	○	○	●	●
Use TV remote control	●	●	●	○	○	○	●
Thread needle	●	●	○	○	○	●	●
Tie off thread	●	●	○	○	●	●	●
Cut paper with scissors	●	○	○	○	●	●	●
Fold paper in half	●	○	○	○	●	●	●
Remove stick of gum from pack	●	○	○	○	●	●	●
Open stick of gum	●	●	○	○	●	●	●
Unlock and open briefcase	●	●	○	○	●	●	○
Close and lock briefcase	●	●	○	○	●	●	●
Put on ring	●	●	○	○	●	●	●
Open and light Zippo	●	●	○	○	●	○	●
Fold paper in thirds	●	●	○	○	●	●	●
Stuff and seal envelope	●	●	○	○	●	●	●
Open envelop with pen	●	○	●	○	●	●	●
Seal bread bag	●	●	○	○	●	●	●
Switch place settings	●	●	○	○	●	●	○
Cut bread	●	●	●	○	●	●	●
Open tea bag	●	●	●	○	●	●	●
Dunk tea bag	●	○	○	○	●	○	○
Squirt toothpaste on brush	●	○	●	○	○	●	●
Open child-proof container	●	●	●	○	●	●	●
Insert Phillips screw	●	●	●	○	●	●	●
Snap picture	●	●	●	○	●	●	●
Salt something	●	○	○	○	○	○	○
Open spin lock	●	●	○	○	●	●	●
Pick up briefcase	●	○	○	○	○	○	○
Put on glasses	●	○	○	○	○	●	○
Take off glasses	●	○	○	○	○	●	○
Put on shoes	●	○	○	○	○	●	○
Tie shoelaces	●	●	●	○	○	●	○
Put on belt	●	●	○	○	●	●	○
Put on dress shirt	●	●	○	○	○	●	●
Button dress shirt	●	●	○	○	●	●	○

APPENDIX G. A/P FOR REAL WORLD TASKS USING THWH

	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement	8. Gross Touch	9. Fine Touch	10. Force Reflection	11. Temperature Discrimination
Type on keyboard	●	●	●	○	○	○	○	●	●	●	○
Type on keypad	●	●	●	○	○	○	○	●	●	●	○
Open door with punch lock	●	●	○	○	●	●	○	●	●	○	○
Use mouse	●	○	●	○	●	○	●	●	●	●	○
Open push door using horizontal handle	●	○	●	○	○	●	○	●	○	○	○
Open pull door using vertical handle	●	○	●	○	○	●	○	●	●	○	○
Open door using key and doorknob	●	●	●	○	●	●	○	●	●	○	○
Open door using doorknob	●	○	●	○	●	○	○	●	○	○	○
Turn light switch off	●	○	○	○	●	○	○	○	●	○	○
Read hardcover book	●	●	○	○	●	●	●	●	●	○	○
Drink from glass	●	○	○	○	○	○	●	●	●	○	○
Drink from mug	●	○	○	○	○	○	●	●	●	○	○
Write with pen on paper	●	●	○	○	●	●	●	●	●	●	●
Cut cucumber	●	○	○	○	●	●	●	●	○	●	●
Butter bread	●	○	○	○	●	●	●	●	○	○	○
Screw lid on jar	●	○	●	○	●	●	○	●	●	○	○
Dial pushbutton phone	●	●	●	○	○	●	●	●	●	●	○
Use TV remote control	●	●	●	○	○	○	●	○	●	●	○
Thread needle	●	●	○	○	○	●	●	●	●	○	○
Tie off thread	●	●	○	○	●	●	●	●	●	○	○
Cut paper with scissors	●	○	○	○	●	●	●	●	○	●	○
Fold paper in half	●	○	○	○	●	●	●	●	●	○	○
Remove stick of gum from pack	●	○	○	○	●	●	●	●	●	●	○
Open stick of gum	●	●	○	○	●	●	●	●	●	●	○
Unlock and open briefcase	●	●	○	○	●	●	○	●	●	●	●
Close and lock briefcase	●	●	○	○	●	●	●	●	●	●	●
Put on ring	●	●	○	○	●	●	●	●	●	○	○
Open and light Zippo	●	●	○	○	●	○	●	●	●	●	○
Fold paper in thirds	●	●	○	○	●	●	●	●	●	●	○
Stuff and seal envelope	●	●	○	○	●	●	●	●	●	●	●
Open envelop with pen	●	○	●	○	●	●	●	●	●	●	●
Seal bread bag	●	●	○	○	●	●	●	●	●	●	●
Switch place settings	●	●	○	○	●	●	○	●	●	●	○
Cut bread	●	●	●	○	●	●	●	●	●	●	●
Open tea bag	●	●	●	○	●	●	●	●	●	●	●
Dunk tea bag	●	○	○	○	●	○	○	●	●	●	●
Squirt toothpaste on brush	●	○	●	○	○	●	●	●	●	○	○
Open child-proof container	●	●	●	○	●	●	●	●	●	●	●
Insert Phillips screw	●	●	●	○	●	●	●	●	●	●	●
Snap picture	●	●	●	○	●	●	●	●	●	●	○
Salt something	●	○	○	○	○	○	○	●	○	●	●
Open spin lock	●	●	○	○	●	●	●	●	●	●	○
Pick up briefcase	●	○	○	○	○	○	○	●	○	●	○
Put on glasses	●	○	○	○	○	●	○	●	●	●	●
Take off glasses	●	○	○	○	○	●	○	●	●	●	●
Put on shoes	●	○	○	○	○	●	○	●	●	●	●
Tie shoelaces	●	●	●	○	○	●	○	●	●	●	●
Put on belt	●	●	○	○	●	●	○	●	●	●	●
Put on dress shirt	●	●	○	○	○	●	●	●	○	○	●
Button dress shirt	●	●	○	○	●	●	○	●	●	●	○

APPENDIX H. SCALED REAL WORLD TASKS USING THWH

	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement	8. Gross Touch	9. Fine Touch	10. Force Reflection	11. Temperature Discrimination
Type on keyboard	6	4	3	1	1	7	1	5	7	6	1
Type on keypad	6	4	3	1	1	1	1	5	7	6	1
Open door with punch lock	7	5	1	1	4	5	1	5	5	1	1
Use mouse	5	1	3	1	3	1	5	5	3	2	1
Open push door using horizontal handle	5	1	3	1	1	2	1	4	1	1	1
Open pull door using vertical handle	5	1	4	1	1	2	1	4	4	1	1
Open door using key and doorknob	5	5	3	1	4	4	4	4	5	1	1
Open door using doorknob	5	1	3	1	3	1	1	4	1	1	1
Turn light switch off	3	1	1	1	2	1	1	1	4	1	1
Read hardcover book	4	4	1	1	2	5	6	5	4	1	1
Drink from glass	5	1	1	1	1	1	5	4	2	1	1
Drink from mug	5	1	1	1	1	1	5	4	5	1	1
Write with pen on paper	4	3	1	1	7	5	4	4	4	2	2
Cut cucumber	3	1	1	1	6	6	6	6	1	6	6
Butter bread	4	1	1	1	4	5	5	5	1	1	1
Screw lid on jar	5	1	4	1	3	3	1	4	3	1	1
Dial pushbutton phone	5	2	2	1	1	4	4	3	4	5	1
Use TV remote control	4	3	2	1	1	1	3	1	5	4	1
Thread needle	4	5	1	1	1	7	7	6	7	1	1
Tie off thread	3	6	1	1	6	7	7	7	7	1	1
Cut paper with scissors	4	1	1	1	4	4	4	4	1	5	1
Fold paper in half	5	1	1	1	2	5	3	5	3	1	1
Remove stick of gum from pack	5	1	1	1	2	3	2	3	4	3	1
Open stick of gum	5	3	1	1	3	5	3	3	5	4	1
Unlock and open briefcase	3	4	1	1	3	5	1	3	4	4	3
Close and lock briefcase	3	5	1	1	4	5	3	4	4	4	3
Put on ring	4	3	1	1	5	5	6	4	5	1	1
Open and light Zippo	5	2	4	1	3	1	5	4	5	7	1
Fold paper in thirds	5	3	1	1	5	4	4	5	4	2	1
Stuff and seal envelope	3	3	1	1	4	4	3	4	5	3	2
Open envelop with pen	3	1	4	1	3	4	4	3	4	3	4
Seal bread bag	3	4	1	1	5	5	3	4	5	6	6
Switch place settings	4	3	1	1	3	5	1	4	3	2	1
Cut bread	3	3	2	1	3	4	4	4	3	3	4
Open tea bag	4	3	2	1	3	4	4	4	4	3	4
Dunk tea bag	3	1	1	1	3	1	1	3	3	4	3
Squirt toothpaste on brush	4	1	3	1	1	4	5	3	3	1	1
Open child-proof container	4	5	5	1	3	5	1	5	5	2	2
Insert Phillips screw	4	5	4	1	5	4	4	4	4	4	4
Snap picture	4	4	4	1	3	5	6	3	4	5	1
Salt something	4	1	1	1	1	1	1	4	1	5	5
Open spin lock	4	5	1	1	7	3	3	4	7	6	1
Pick up briefcase	4	1	1	1	1	1	1	5	1	4	1
Put on glasses	4	1	1	1	1	4	1	4	4	3	3
Take off glasses	4	1	1	1	3	4	2	4	4	3	3
Put on shoes	4	1	1	1	1	5	1	4	3	3	4
Tie shoelaces	4	4	3	1	1	6	1	5	6	6	5
Put on belt	4	4	1	1	4	5	1	5	5	4	4
Put on dress shirt	5	4	1	1	1	4	3	4	1	1	4
Button dress shirt	4	6	1	1	5	6	1	5	6	6	1

APPENDIX I. A/P FOR MULTIPLE DEVICES

	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement	8. Gross Touch	9. Fine Touch	10. Force Reflection	11. Temperature Discrimination
Virtual Technologies CyberGlove	●	○	○	●	●	●	○	○	○	○	○
Virtual Technologies CyberTouch	●	○	○	●	●	●	○	●	○	●	○
Sensable Devices PHANToM	●	○	●	○	○	●	●	●	●	●	○
Japansese PIN thing in VRAIS	○	○	○	○	○	○	○	●	●	○	○
Virtual Technologies CyberGloves & Tracker	●	●	●	●	●	●	●	○	○	○	○
Virtual Technologies CyberTouchs & Tracker	●	●	●	●	●	●	●	●	○	●	○
Sensable Devices PHANToMs	●	●	●	○	○	●	●	●	●	●	○

APPENDIX J. SCALED FOR MULTIPLE DEVICES

	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement	8. Gross Touch	9. Fine Touch	10. Force Reflection	11. Temperature Discrimination
Virtual Technologies CyberGlove	3	1	1	4	4	4	1	1	1	1	1
Virtual Technologies CyberTouch	3	1	1	4	4	4	1	2	1	3	1
Sensable Devices PHANToM	4	1	3	1	1	4	3	3	4	4	1
Japansese PIN thing in VRAIS	1	1	1	1	1	1	1	1	1	1	1
Virtual Technologies CyberGloves & Tracker	3	4	3	4	4	4	4	2	1	3	1
Virtual Technologies CyberTouchs & Tracker	4	3	3	1	1	4	3	3	4	4	1
Sensable Devices PHANToMs	4	3	3	1	1	4	3	3	4	4	1

APPENDIX K. ANALYSIS OF SOLDIER'S MANUAL — CMF 91 GENERAL MEDICAL TASKS

A. INTRODUCTION

This Appendix presents the preliminary version of a study which applies a two-handed, whole-hand taxonomy to the Soldier Training Publication, Soldier's Manual — CMF 91 General Medical Tasks. The training manual contains "critical tasks for soldiers holding MOSs...91B...."[STP88] The manual was developed to promote and test proficiency in tasks deemed appropriate to the covered MOSs (jobs). The manual presents "standardized training objectives" as lists of task summaries.[STP88] These tasks summaries are used by trainers and trainees to "evaluate critical tasks which support unit missions during wartime."[STP88]

The application of the taxonomy to this manual is an attempt to explicate and codify the human abilities required

B. NOTES ON MANUAL

The manual, Soldier's Manual — CMF 91 General Medical Tasks, contains inconsistencies in grammar, in the level of tasks presented, and in references to other tasks. These inconsistencies were carrier over from the manual in the section General Medical Tasks.

C. GENERAL MEDICAL TASKS

The tasks presented in this section are numbered as they are presented in the manual. The wording is exact, unless noted by an "...". In all cases, the information removed does not enhance understanding of the task.

The human abilities required to perform the task are presented to the right of the task. All human abilities are in *italics*.

A rating of NA for human abilities signals a number of situations:

- The task is a note to repeat already completed tasks.
- The task is too broad for breakdown.
- There are too many different ways to perform the task.
- The task points to another task.

The rating of NA is never given if none of the human abilities apply. In the case that none of the human abilities defined in the THWH taxonomy apply to the task in the manual, then the rating NONE is given.

The notation "—" signifies that the task is broken down below and the human abilities are attached to the more refined tasks.

081-831-0007 Perform a Patient Care Handwash

1. Removes wristwatch and jewelry, if applicable.	*Gross touch, Fine touch, Multilimb coordination,* Arm-hand steadiness, Manual dexterity, Finger dexterity
2. Rolls shirt sleeves to above the elbows, if applicable.	*Gross touch, Multilimb coordination, Arm-hand steadiness,* Manual dexterity
3. Prepares to perform the handwash.	*Gross touch, Control Precision, Manual dexterity*
4. Wets the hands, wrists, and forearms.	*Gross touch, Multilimb coordination, Arm-hand steadiness*
5. Covers the hands, wrists, and forearms with soap.	*Gross touch, Multilimb coordination*
6. Washes the hands, wrists, and forearms.	*Gross touch, Multilimb coordination*
7. Rinses the hands, wrists, and forearms.	*Gross touch, Arm-hand steadiness*
8. Dries the hands, wrists, and forearms.	*Gross touch, Multilimb coordination, Arm-hand steadiness*
9. Uses a towel to turn off the running water, if applicable.	*Gross touch, Control Precision, Manual dexterity*
10. Reinspects the fingernails, and cleans them and rewashs the hands, if necessary.	NA - Too many ways

081-831-0008 Put On and Remove Sterile Gloves

1. Selects and inspects the package.	*Gross touch, Arm-hand steadiness, Manual dexterity*
2. Performs a patient care handwash.	NA — See 081-0008-0007
3. Opens the sterile package.	*Gross touch, Multilimb coordination, Arm-hand steadiness, Manual dexterity, Finger dexterity*
4. Positions the inner package.	*Gross touch, Fine touch, Multilimb coordination, Manual dexterity, Finger dexterity*
5. Unfolds the inner package.	*Gross touch, Fine touch, Multilimb coordination, Manual dexterity, Finger dexterity*
6. Exposes both gloves.	*Gross touch, Fine touch, Multilimb coordination, Manual dexterity, Finger dexterity*
7. Puts on the first glove.	*Gross touch, Fine touch, Multilimb coordination, Arm-hand steadiness, Manual dexterity, Finger dexterity*
8. Puts on the second glove.	*Gross touch, Fine touch, Multilimb coordination,* Arm-hand steadiness, Manual dexterity, Finger dexterity
9. Adjusts the glove to fit properly.	*Gross touch, Multilimb coordination, Arm-hand steadiness, Manual dexterity, Finger dexterity*
10. Remove the gloves.	*Gross touch, Fine touch, Multilimb coordination, Arm-hand steadiness, Manual dexterity, Finger dexterity*

11. Discards the gloves IAW local SOP.	NONE
12. Performs a patient care handwash.	NA — See 081-0008-0007

081-831-037 Disinfect Water for Drinking

1. Mixes the stock disinfecting solution.	NA — Too broad / Too many ways
2. Adds the stock solution to the water container.	*Gross touch, Force reflection, Arm-hand steadiness, Manual dexterity*
3. Flushes the faucets.	NA — Too many ways
4. Tests the chlorine residual after 10 minutes.	NA — Too broad
5. Retests the chlorine residual after 20 minutes.	NA — See step 4
6. Retests the water two or three times daily.	NA — See step 4

081-831-0013 Measure and Record a Patient's Temperature

1. Determines which site to use.	NONE
2. Selects the proper thermometer.	NONE
3. Explains the procedure and positions the patient.	NONE
4. Measures the temperature.	—
a. Shakes the thermometer down to below 94° F	*Gross touch, Wrist-finger speed*
b. Places the thermometer at the proper site.	*Gross touch, Force reflection, Control precision,* Arm-hand steadiness, Manual dexterity, Finger dexterity
5. Remove the thermometer and wipes it down with gauze square.	*Gross touch, Arm-hand steadiness, Finger dexterity*
6. Reads the scale.	*Gross touch, Arm-hand steadiness*
7. Puts the thermometer in the proper "used" canister.	*Gross touch, Control precision, Manual dexterity*
8. Records the temperature to the nearest 0.2° F on the appropriate forms and reports any abnormal temperature change immediately to the supervisor.	NA — See task 081-831-0033

081-831-0011 Measure and Record a Patient's Pulse

1. Positions the patient so that the pulse site is accessible.	NA — Too many ways
2. Palpates the pulse site.	*Gross touch, Fine touch, Force reflection, Multilimb coordination,* Arm-hand steadiness
3. Counts for 1 full minute and evaluates the pulse.	*Gross touch, Fine touch, Force reflection, Arm-hand steadiness*
4. Records the rate, rhythm, strength, and any significant deviations from normal	NA — See task 081-831-0033

on the appropriate forms.	
5. Reports any significant pulse abnormalities to the supervisor immediately.	NONE

081-831-0010 Measure and Record a Patient's Respirations

1.Counts the number of times the chest rises in 1 minute.	NONE
2. Evaluate the respirations.	NONE
3. Checks for the physical characteristics of abnormal respirations.	NONE
4. Records the rate of respirations and any observations noted on the appropriate forms.	NA — See task 081-831-0033
5. Reports abnormal respirations to the supervisor immediately.	NONE

081-831-0012 Measure and Record a Patient's Blood Pressure

1. Explains the procedure to the patient, if necessary.	NONE
2. Checks the equipment.	*Gross touch, Fine touch, Control precision, Multilimb coordination,* Manual dexterity, Finger dexterity
3. Positions the patient.	NA — Too many ways
4. Places the cuff at the brachial artery site.	*Gross touch, Control precision, Multilimb coordination,* Arm-hand steadiness, Manual dexterity, Finger dexterity
5. Positions the stethoscope, if used.	*Gross touch, Fine touch, Force reflection, Control precision,* Manual dexterity, Finger dexterity
6. Inflates the cuff until the gauge reads at least 140 mm Hg or 10 mm Hg higher than the usual range for that patient, if known.	*Gross touch, Arm-hand steadiness, Manual dexterity*
7. Determines the blood pressure.	NONE
8. Records the blood pressure on the appropriate forms.	NA — See task 081-831-0033
9. Evaluates the blood pressure reading .... [by comparison]	NONE
10. Reports abnormal readings to the supervisor.	NONE

081-831-0047 Evaluate a Patient

1. Check the patient for responsiveness.	—
a. Gently shake the patient's shoulder	*Gross touch, Control precision*
2. Check for breathing.	NONE
3. Check for bleeding.	NA — Too many ways

4. Check for shock.	NA — Too many ways
a. Cool, clammy skin	(Note 1 — See end)
5. Check for fractures.	NA — Too many ways
6. Check for burns.	NA — Too many ways
7. Check for head injury.	NONE
8. Check the vital signs. (See tasks 081-831-0010, 081-831-0011, and 081-831-0012.)	NA — See tasks 081-831-0010, 081-831-0011, and 081-831-0012
9. Check for symptoms of substance abuse.	NONE
10. Record the treatment given and observations noted on the Field Medical Card. (See task 081-831-0033.)	NA — See task 081-831-0033
11. Evacuate the patient, if necessary.	NA — Too broad

081-831-0018 Open the Airway

1. Rolls the casualty onto his or her back, if necessary.	NA — Too many approaches
2. Establishes the airway, using one of the methods below:	—
a. Head-tilt/chin-list method.	*Gross touch, Force reflection, Control precision,* Multilimb coordination, Arm-hand steadiness, Manual dexterity
b. Jaw thrust.	*Gross touch, Force reflection, Control precision,* Multilimb coordination, Arm-hand steadiness, Manual dexterity
3. Checks for breathing within 3 to 5 seconds. While maintaining the open airway position, places an ear over the casualty's mouth and nose, looking towards the chest and stomach.	NONE
4. Takes appropriate action.	NA — Way too broad

081-831-0019 Clear an Upper Airway Obstruction

1. Clear the airway.	—
Conscious Casualty	
1. Determine whether the casualty needs help. Ask whether he or she is choking.	NONE
2. If the casualty is lying down, bring him or her to a sitting or standing position.	NA — Too many ways
3. Apply abdominal or chest thrusts.	*Gross touch, Fine touch, Force reflection, Multilimb coordination,*

	Speed of limb movement
Unconscious Casualty	
1. Apply abdominal or chest thrusts.	*Gross touch, Fine touch, Force reflection, Multilimb coordination,* Speed of limb movement
2. Perform a finger sweep.	*Gross touch, Fine touch, Finger dexterity*
3. Attempt to ventilate.	NA — See tasks 1 and 2
2. When the object is dislodged, check for breathing.	NONE

081-831-0048 Perform Rescue Breathing

1. Ventilates the casualty using mouth-to-mouth or mouth-to-nose method, as appropriate.	NA — Too many ways
2. Repositions the head to ensure an open airway and repeats step 1, if necessary.	*Gross touch, Force reflection, Control precision, Multilimb coordination, Arm-hand steadiness, Manual dexterity*
3. Clears an airway obstruction, if necessary. (See task 081-831-0019.) When the obstruction has been cleared, continues with step 4.	NA — See task 081-831-0019
4. Checks the carotid pulse for 5 to 10 seconds.	*Gross touch, Fine touch, Force reflection, Arm-hand steadiness*
5. Continues rescue breathing.	NONE

081-831-0046 Administer External Chest Compressions

One Rescuer CPR	
1. Ensure that the casualty is positioned on a hard flat surface.	NA — Too many ways
2. Position the hands for external chest compressions.	*Gross touch, Multilimb coordination*
3. Position the body.	NA — Too many ways
4. Give 15 compressions.	*Gross touch, Force reflection, Multilimb coordination,* Arm-hand steadiness, Speed of limb movement
5. Give two full breaths.	NONE
6. Repeat steps 1 through 5 four times.	NA — See steps 1 to 5
7. Assess the casualty.	NONE
8. Resume CPR with two breathes followed by compressions.	NA — Too broad, See step 4 for compressions
9. Recheck for pulse every 3 to 5 minutes.	*Gross touch, Fine touch, Force reflection, Arm-hand steadiness*
10. Continue to alternate chest compressions	NA — Too broad. See step 4 for compressions

and rescue breathing until:...

Two-rescuer CPR.

1. Compressor: Give five chest compressions at the rate of 80 to 100 per minute.	*Gross touch, Force reflection, Multilimb coordination, Arm-hand steadiness, Speed of limb movement*
Ventilator: Maintain an open airway and monitor the carotid pulse occasionally for adequacy of chest compressions.	*Gross touch, Fine touch, Force reflection, Control precision, Multilimb coordination, Arm-hand steadiness, Manual dexterity*
2. Compressor: Pause.	NONE
Ventilator: Give one full breath (1 to 1.5 seconds).	NA — Too many ways
3. Compressor: Continue to give chest compressions until a change position is initiated.	*Gross touch, Force reflection, Multilimb coordination, Arm-hand steadiness, Speed of limb movement*
Ventilator: Continue to give ventilations until the compressor indicates that a change is to be made.	NA — Too many ways
4. Compressor: Give a clear signal to change positions.	NONE
Ventilator: Remain in the rescue breathing position.	NONE
5. Compressor: Give the fifth compression.	*Gross touch, Force reflection, Multilimb coordination,* Arm-hand steadiness, Speed of limb movement
Ventilator: Give the breath following the fifth compression.	NA — Too many ways
6. Compressor and ventilator simultaneously switch positions.	NONE
7. New Ventilator: Check the casualty's carotid pulse for 5 seconds.	*Gross touch, Fine touch, Force reflection, Arm-hand steadiness*
New Compressor: Position the hands to being chest compressions as directed by the ventilator.	*Gross touch, Multilimb coordination*
8. Ventilator: Continue to give one breath on each fifth upstroke of chest compressions, and ensure that the chest rises.	NONE
Compressor: Continue to give chest compressions at the rate of 80 to 100 per minute.	*Gross touch, Force reflection, Multilimb coordination, Arm-hand steadiness, Speed of limb movement*
9. Continue to perform CPR as stated in the task standard.	NA — See steps 1 to 8
10. When the pulse and breathing are restored, the soldier would continue	NA — See task 081-831-0047

to evaluate the casualty.
(See task 081-831-0047.)

081-831-0043 Immobilize a Suspected Dislocated and/or Fractured Ankle Using a Wire Ladder Splint.

1. Cuts the boot laces until all laces are separated. [Using knife]	*Gross touch, Fine touch, Force reflection, Control precision, Multilimb coordination, Arm-hand steadiness, Manual dexterity,* Finger-dexterity, Wrist-finger speed
2. Cuts the boot tongue from the top to the bottom.	*Gross touch, Fine touch, Force reflection, Control precision, Multilimb coordination, Arm-hand steadiness, Manual dexterity,* Finger-dexterity, Wrist-finger speed
3. Checks for a pedal pulse. (See task 081-831-0011.)	NA — See task 081-831-0011
4. Prepares the splint.	*Gross touch, Fine touch, Force reflection, Control precision,* Multilimb coordination, Arm-hand steadiness, Manual dexterity
5. Applies the splint around the casualty's ankle.	*Gross touch, Fine touch, Force reflection, Control precision,* Multilimb coordination, Arm-hand steadiness, Manual dexterity
6. Ties the first cravat around the splints.	*Gross touch, Fine touch, Force reflection, Control precision,* Multilimb coordination, Manual dexterity, Finger dexterity
7. Checks the pedal pulse.	NA — See task 081-831-0011
8. Ties the second cravat.	*Gross touch, Fine touch, Force reflection, Control precision,* Multilimb coordination, Manual dexterity, Finger dexterity
9. Checks the pedal pulse IAW step 7.	NA — See task 081-831-0011
10. Ties the third cravat.	*Gross touch, Fine touch, Force reflection, Control precision,* Multilimb coordination, Manual dexterity, Finger dexterity
11. Check the pedal pulse IAW step 7.	NA — See task 081-831-0011
12. Records the treatment given.	NA — See task 081-831-0033

081-831-0044 Apply a Pneumatic Splint to a Casualty with a Suspected Fracture of an Extremity

1. Check the equipment both visually and manually for...	*Gross touch, Fine touch, Control precision, Multilimb coordination, Finger dexterity*
2. Opens the splint completely and places it next to the injured extremity.	NA — Too many ways
3. Lifts and supports the injured extremity.	*Gross touch, Force reflection, Control precision,* Multilimb coordination, Arm-hand steadiness, Manual dexterity
4. Positions the splint under the injured extremity and positions the splint around the injured area.	*Gross touch, Force reflection, Control precision, Multilimb coordination, Arm-hand steadiness, Manual dexterity*
5. Inflates the splint.	*Gross touch, Arm-hand steadiness, Manual dexterity*

6. Monitors the splint.	NONE
7. Checks for peripheral circulation.	*Gross touch, Fine touch, Force reflection, Multilimb coordination,* Arm-hand steadiness

081-831-0033 Initiates a Field Medical Card

1. Remove the protective sheet from the carbon copy.	*Gross touch., Fine touch, Control precision, Multilimb coordination, Arm-hand steadiness, Manual dexterity, Finger dexterity*
2. Complete the minimum required blocks.	*Gross touch, Control precision, Arm-hand steadiness,* Manual dexterity, Finger dexterity
3. Complete the other blocks as time permits.	*Gross touch, Control precision, Arm-hand steadiness,* Manual dexterity, Finger dexterity
4. Keep the flimsy white filled-out copy.	NONE
5. Affix the hard copy with attached wire to casualty.	*Gross touch, Fine touch, Control precision, Multilimb coordination,* Arm-hand steadiness, Manual dexterity, Finger dexterity

081-831-0035 Manage a Convulsive and/or Seizing Patient

1. Identifies the type of convulsions and/or seizures based upon...characteristic signs and symptoms.	NONE
2. Maintains the airway of a patient exhibiting tonic-clonic movement.	*Gross touch, Force reflection, Control precision, Multilimb coordination, Arm-hand steadiness, Manual dexterity*
3. Places the patient on his or her side if possible.	NA — Too many ways
4. Prevents injury to tissue and bones by padding or removing objects on which the patient may injure himself or herself.	NA — Too many ways
5. Manages the patient after the convulsive state has ended.	NONE
6. Records the seizure activity.	NA — See task 081-831-0033
7. Evacuates the patient.	NA

081-831-0038 Treat a Casualty for a Heat Injury

1. Identifies the type of heat injury based upon...characteristic signs and symptoms.	NONE
2. Provides the proper first aid for heat injury.	NA — Too broad
3. Records the treatment given. (See task 081-831-0033.)	NA — See task 081-831-0033

081-831-0039 Treat a Casualty for a Cold Injury

1. Recognizes the signs and symptoms of cold injuries.	NA — Too broad
2. Treat the cold injury.	NA — Too broad

NOTES

1 — This is a very good example of when a task-specific skill is needed that was not codified in the general taxonomy. The hands are used in this situation to feel for temperature and for moisture.

APPENDIX L. A/P FOR MEDIC ANALYSIS USING THWH

	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement	8. Gross Touch	9. Fine Touch	10. Force Reflection	11. Temperature Discrimination
081-831-0007 Perform a Patient Care Handwash											
1. Removes wristwatch and jewelry, if applicable.	○	●	●	●	●	○	○	●	●	○	○
2. Rolls shirt sleeves to above the elbows, if applicable.	○	●	●	●	○	○	○	●	○	○	○
3. Prepares to perform the handwash.	●	○	○	●	○	○	○	●	○	○	○
4. Wets the hands, wrists, and forearms.	○	●	●	○	○	○	○	●	○	○	○
5. Covers the hands, wrists, and forearms with soap.	○	●	○	○	○	○	○	●	○	○	○
6. Washes the hands, wrists, and forearms.	○	●	○	○	○	○	○	●	○	○	○
7. Rinses the hands, wrists, and forearms.	○	○	●	○	○	○	○	●	○	○	○
8. Dries the hands, wrists, and forearms.	○	●	●	○	○	○	○	●	○	○	○
9. Uses a towel to turn off the running water, if applicable.	●	○	○	●	○	○	○	●	○	○	○
10. Reinspects the fingernails, and cleans them and rewashs the hands...	N/A - Too many ways										
081-831-0008 Put On and Remove Sterile Gloves											
1. Selects and inspects the package.	○	○	●	●	○	○	○	●	○	○	○
2. Performs a patient care handwash.	N/A - See 081-0008-0007										
3. Opens the sterile package.	○	●	●	●	●	○	○	●	○	○	○
4. Positions the inner package.	○	●	○	●	●	○	○	●	●	○	○
5. Unfolds the inner package.	○	●	○	●	●	○	○	●	●	○	○
6. Exposes both gloves.	○	●	○	●	●	○	○	●	●	○	○
7. Puts on the first glove.	○	●	●	●	●	○	○	●	●	○	○
8. Puts on the second glove.	○	●	●	●	●	○	○	●	●	○	○
9. Adjusts the glove to fit properly.	○	●	●	●	●	○	○	●	○	○	○
10. Remove the gloves.	○	●	●	●	●	○	○	●	●	○	○
11. Discards the gloves IAW local SOP.	○	○	○	○	○	○	○	○	○	○	○
12. Performs a patient care handwash.	N/A - See 081-0008-0007										
081-831-037 Disinfect Water for Drinking											
1. Mixes the stock disinfecting solution.	N/A - Too broad / Too many ways										
2. Adds the stock solution to the water container.	○	○	●	●	○	○	○	●	○	●	○
3. Flushes the faucets.	N/A - Too many ways										
4. Tests the chlorine residual after 10 minutes.	N/A - Too broad										
5. Retests the chlorine residual after 20 minutes.	N/A - See Step 4										
6. Retests the water two or three times daily.	N/A - See Step 4										
081-831-0013 Measure and Record a Patient's Temperature											
1. Determines which site to use.	○	○	○	○	○	○	○	○	○	○	○
2. Selects the proper thermometer.	○	○	○	○	○	○	○	○	○	○	○
3. Explains the procedure and positions the patient.	○	○	○	○	○	○	○	○	○	○	○
4. Measures the temperature.											
a. Shakes the thermometer down to below 94° F	○	○	○	○	○	●	○	●	○	○	○
b. Places the thermometer at the proper site.	●	○	●	●	●	○	○	●	○	●	○
5. Remove the thermometer and wipes it down with gauze square.	○	○	●	○	●	○	○	●	○	○	○
6. Reads the scale.	○	○	●	○	○	○	○	●	○	○	○
7. Puts the thermometer in the proper "used" canister.	●	○	○	●	○	○	○	●	○	○	○
8. Records the temperature to the nearest 0.2° F on the appropriate forms and reports any abnormal temperature change immediately to the supervisor.	N/A - See 081-831-0033										

A/P FOR MEDIC ANALYSIS USING THWH (CONTINUED)

Task	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement	8. Gross Touch	9. Fine Touch	10. Force Reflection	11. Temperature Discrimina
081-831-0011 Measure and Record a Patient's Pulse											
1. Positions the patient so that the pulse site is accessible.	N/A - Too many ways										
2. Palpates the pulse site.	○	●	●	○	○	○	○	●	●	●	○
3. Counts for 1 full minute and evaluates the pulse.	○	○	●	○	○	○	○	●	●	●	○
4. Records the rate, rhythm, strength, and any significant deviations from normal on the appropriate forms.	N/A - See 081-831-0033										
5. Reports any significant pulse abnormalities to the supervisor immediately.	○	○	○	○	○	○	○	○	○	○	○
081-831-0010 Measure and Record a Patient's Respirations											
1.Counts the number of times the chest rises in 1 minute.	○	○	○	○	○	○	○	○	○	○	○
2. Evaluate the respirations.	○	○	○	○	○	○	○	○	○	○	○
3. Checks for the physical characteristics of abnormal respirations.	○	○	○	○	○	○	○	○	○	○	○
4. Records the rate of respirations and any observations noted on the appropriate forms.	N/A - See 081-831-0033										
5. Reports abnormal respirations to the supervisor immediately.	○	○	○	○	○	○	○	○	○	○	○
081-831-0012 Measure and Record a Patient's Blood Pressure											
1. Explains the procedure to the patient, if necessary.	○	○	○	○	○	○	○	○	○	○	○
2. Checks the equipment.	●	●	○	●	●	○	○	●	●	○	○
3. Positions the patient.	N/A - Too many ways										
4. Places the cuff at the brachial artery site.	●	●	●	●	●	○	○	●	○	○	○
5. Positions the stethoscope, if used.	●	○	○	●	●	○	○	●	●	●	○
6. Inflates the cuff until the gauge reads at least 140 mm Hg or 10 mm Hg higher than the usual range for that patient, if known.	○	○	●	●	○	○	○	●	○	○	○
7. Determines the blood pressure.	○	○	○	○	○	○	○	○	○	○	○
8. Records the blood pressure on the appropriate forms.	N/A - See 081-831-0033										
9. Evaluates the blood pressure reading .... [by comparison]	○	○	○	○	○	○	○	○	○	○	○
10. Reports abnormal readings to the supervisor.	○	○	○	○	○	○	○	○	○	○	○
081-831-0047 Evaluate a Patient											
1. Check the patient for responsiveness.											
a. Gently shake the patient's shoulder	●	○	○	○	○	○	○	●	○	○	○
2. Check for breathing.	○	○	○	○	○	○	○	○	○	○	○
3. Check for bleeding.	N/A - Too many ways										
4. Check for shock.	N/A - Too many ways										
a. Cool, clammy skin	●	○	●	○	○	○	○	●	○	○	●
5. Check for fractures.	N/A - Too many ways										
6. Check for burns.	N/A - Too many ways										
7. Check for head injury.	○	○	○	○	○	○	○	○	○	○	○
8. Check the vital signs. (See tasks 081-831-0010, 081-831-0011, and 081-831-0012.)	N/A - See 081-831-0010/0011/0012										
9. Check for symptoms of substance abuse.	○	○	○	○	○	○	○	○	○	○	○
10. Record the treatment given and observations noted on the Field Medical Card. (See task 081-831-0033.)	N/A - See 081-831-0033										
11. Evacuate the patient, if necessary.	N/A - Too broad										

A/P FOR MEDIC ANALYSIS USING THWH (CONTINUED)

Task	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement	8. Gross Touch	9. Fine Touch	10. Force Reflection	11. Temperature Discrimination
081-831-0018 Open the Airway											
1. Rolls the casualty onto his or her back, if necessary.	N/A - Too many ways										
2. Establishes the airway, using one of the methods below:											
a. Head-tilt/chin-list method.	●	●	●	●	○	○	○	●	○	●	○
b. Jaw thrust.	●	●	●	●	○	○	○	●	○	●	○
3. Checks for breathing within 3 to 5 seconds. While maintaining the open airway position, places an ear over the casualty's mouth and nose, looking towards the chest and stomach.	○	○	○	○	○	○	○	○	○	○	○
4. Takes appropriate action.	N/A - Way too broad										
081-831-0019 Clear an Upper Airway Obstruction											
1. Clear the airway.											
Conscious Casualty											
1. Determine whether the casualty needs help. Ask whether he or she is choking.	○	○	○	○	○	○	○	○	○	○	○
2. If the casualty is lying down, bring him or her to a sitting or standing position.	N/A - Too many ways										
3. Apply abdominal or chest thrusts.	○	●	○	○	○	○	●	●	●	●	○
Unconscious Casualty											
1. Apply abdominal or chest thrusts.	○	●	○	○	○	○	●	●	●	●	○
2. Perform a finger sweep.	○	○	○	○	●	○	○	●	●	○	○
3. Attempt to ventilate.	N/A - See previous tasks										
2. When the object is dislodged, check for breathing.	○	○	○	○	○	○	○	○	○	○	○
081-831-0048 Perform Rescue Breathing.											
1. Ventilates the casualty using mouth-to-mouth or mouth-to-nose method, as appropriate.	N/A - Too many ways										
2. Repositions the head to ensure an open airway and repeats step 1, if necessary.	●	●	●	●	○	○	○	●	○	●	○
3. Clears an airway obstruction, if necessary. (See task 081-831-0019.) When the obstruction has been cleared,continues with step 4.	N/A - See 081-831-0019										
4. Checks the carotid pulse for 5 to 10 seconds.	○	○	●	○	○	○	○	●	●	●	○
5. Continues rescue breathing.	○	○	○	○	○	○	○	○	○	○	○
081-831-0043 Immobilize a Suspected Dislocated and/or Fractured Ankle Using a Wire Ladder Splint.											
1. Cuts the boot laces until all laces are separated. [Using knife]	●	●	●	●	●	●	○	●	●	●	○
2. Cuts the boot tongue from the top to the bottom.	●	●	●	●	●	●	○	●	●	●	○
3. Checks for a pedal pulse. (See task 081-831-0011.)	N/A - See 081-831-0011										
4. Prepares the splint.	●	●	●	●	○	○	○	●	●	●	○
5. Applies the splint around the casualty's ankle.	●	●	●	●	○	○	○	●	●	●	○
6. Ties the first cravat around the splints.	●	●	○	●	●	○	○	●	●	●	○
7. Checks the pedal pulse.	N/A - See 081-831-0011										
8. Ties the second cravat.	●	●	○	●	●	○	○	●	●	●	○
9. Checks the pedal pulse IAW step 7.											
10. Ties the third cravat.	○	○	○	○	○	○	○	●	●	●	○
11. Check the pedal pulse IAW step 7.	N/A - See 081-831-0011										
12. Records the treatment given.	N/A - See 081-831-0033										

A/P FOR MEDIC ANALYSIS USING THWH (CONTINUED)

Task	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement	8. Gross Touch	9. Fine Touch	10. Force Reflection	11. Temperature Discrimina
081-831-0046 Administer External Chest Compressions											
One Rescuer CPR											
1. Ensure that the casualty is positioned on a hard flat surface.	N/A - Too many ways										
2. Position the hands for external chest compressions.	○	●	○	○	○	○	○	●	○	○	○
3. Position the body.	N/A - Too many ways										
4. Give 15 compressions.	○	●	●	○	○	○	●	●	○	●	○
5. Give two full breaths.	○	○	○	○	○	○	○	○	○	○	○
6. Repeat steps 1 through 5 four times.	N/A - See steps 1 through 5										
7. Assess the casualty.	○	○	○	○	○	○	○	○	○	○	○
8. Resume CPR with two breathes followed by compressions.	N/A - Too broad, see step 4 for compressions										
9. Recheck for pulse every 3 to 5 minutes.	○	○	●	○	○	○	○	●	●	●	○
10. Continue to alternate chest compressions and rescue breathing until:...	N/A - Too broad, see step 4 for compressions										
Two-rescuer CPR.											
1. Compressor: Give five chest compressions at the rate of 80 to 100 per minute.	○	●	●	○	○	○	●	●	○	●	○
Ventilator: Maintain an open airway and monitor the carotid pulse occasionally for adequacy of chest compressions.	●	●	●	●	○	○	○	●	●	●	○
2. Compressor: Pause.	○	○	○	○	○	○	○	○	○	○	○
Ventilator: Give one full breath (1 to 1.5 seconds).	N/A - Too many ways										
3. Compressor: Continue to give chest compressions until a change position is initiated.	○	●	●	○	○	○	●	●	○	●	○
Ventilator: Continue to give ventilations until the compressor indicates that a change is to be made.	N/A - Too many ways										
4. Compressor: Give a clear signal to change positions.	○	○	○	○	○	○	○	○	○	○	○
Ventilator: Remain in the rescue breathing position.	○	○	○	○	○	○	○	○	○	○	○
5. Compressor: Give the fifth compression.	○	●	●	○	○	○	●	●	○	●	○
Ventilator: Give the breath following the fifth compression.	N/A - Too many ways										
6. Compressor and ventilator simultaneously switch positions.	○	○	○	○	○	○	○	○	○	○	○
7. New Ventilator: Check the casualty's carotid pulse for 5 seconds.	○	○	●	○	○	○	○	●	●	●	○
New Compressor: Position the hands to being chest compressions as directed by the ventilator.	○	●	○	○	○	○	○	●	○	○	○
8. Ventilator: Continue to give one breath on each fifth upstroke of chest compressions, and ensure that the chest rises.	○	○	○	○	○	○	○	○	○	○	○
Compressor: Continue to give chest compressions at the rate of 80 to 100 per minute.	○	●	●	○	○	○	●	●	○	●	○
9. Continue to perform CPR as stated in the task standard.	N/A - See steps 1 through 8										
10. When the pulse and breathing are restored, the soldier would continue to evaluate the casualty. (See task 081-831-0047.)	N/A - See 081-831-0047										

A/P FOR MEDIC ANALYSIS USING THWH (CONTINUUED)

Task	1. Control Precision	2. Multilimb Coordination	3. Arm-hand Steadiness	4. Manual Dexterity	5. Finger Dexterity	6. Wrist-finger Speed	7. Speed of Limb Movement	8. Gross Touch	9. Fine Touch	10. Force Reflection	11. Temperature Discrimination
081-831-0044 Apply a Pneumatic Splint to a Casualty with a Suspected Fracture of an Extremity											
1. Check the equipment both visually and manually for...	●	●	○	○	●	○	○	●	●	○	○
2. Opens the splint completely and places it next to the injured extremity.	N/A - Too many ways										
3. Lifts and supports the injured extremity.	●	●	●	●	○	○	○	●	○	●	○
4. Positions the splint under the injured extremity and positions the splint around the injured area.	●	●	●	●	○	○	○	●	○	●	○
5. Inflates the splint.	○	○	●	●	○	○	○	○	○	●	○
6. Monitors the splint.	○	○	○	○	○	○	○	○	○	○	○
7. Checks for peripheral circulation.	○	●	●	○	○	○	○	●	●	●	○
081-831-0033 Initiates a Field Medical Card											
1. Remove the protective sheet from the carbon copy.	●	●	●	●	●	○	○	●	●	○	○
2. Complete the minimum required blocks.	●	○	●	●	●	○	○	●	○	○	○
3. Complete the other blocks as time permits.	●	○	●	●	●	○	○	●	○	○	○
4. Keep the flimsy white filled-out copy.	○	○	○	○	○	○	○	○	○	○	○
5. Affix the hard copy with attached wire to casualty.	●	●	●	●	○	○	○	●	●	○	○
081-831-0035 Manage a Convulsive and/or Seizing Patient											
1. Identifies the type of convulsions and/or seizures based upon...characteristic signs and symptoms.	○	○	○	○	○	○	○	○	○	○	○
2. Maintains the airway of a patient exhibiting tonic-clonic movement.	●	●	●	●	○	○	○	●	○	●	○
3. Places the patient on his or her side if possible.	N/A - Too many ways										
4. Prevents injury to tissue and bones by padding or removing objects on which the patient may injure himself or herself.	N/A - Too many ways										
5. Manages the patient after the convulsive state has ended.	○	○	○	○	○	○	○	○	○	○	○
6. Records the seizure activity.	N/A - See 081-831-0033										
7. Evacuates the patient.	N/A - Way too broad										
081-831-0038 Treat a Casualty for a Heat Injury											
1. Identifies the type of heat injury based upon...characteristic signs and symptoms.	○	○	○	○	○	○	○	○	○	○	○
2. Provides the proper first aid for heat injury.	N/A - Too broad										
3. Records the treatment given. (See task 081-831-0033.)	N/A - See 081-831-0033										
081-831-0039 Treat a Casualty for a Cold Injury											
1. Recognizes the signs and symptoms of cold injuries.	N/A - Too broad										
2. Treat the cold injury.	N/A - Too broad										

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